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An evaluation of the benefits and costs of in-field shelterbelts in Midwestern USA

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An evaluation of the benefits and costs of in-field shelterbelts in Midwestern USA

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Signature was redacted for privacy.

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For the Major Program

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

Selected field windbreak (shelterbelt) designs were evaluated to assess their cost effectiveness of providing additional crop production, carbon sequestration, and hunting opportunities.

In terms of additional crop production, a three-row mixed windbreak with extensive management and low cost is the most cost effective because it requires the smallest corn yield increases to break even. Using a sheltering effect of 12 windbreak heights, the required additional yield is 0.28 Mg ha^{-1} yr^{-1}. A four-row spruce windbreak with intensive management and high costs is the least cost effective because it requires the largest corn yield increases that are 28 times larger than those of the mixed windbreak. Trees that grow faster and taller are more cost effective because they provide sheltering effect sooner and over larger distances allowing to break even with smaller yield increases that are more likely to be achieved.

In terms of carbon sequestration, a four-row cottonwood windbreak is the most cost effective because it accumulates the greatest amounts of above and below-ground carbon that allow it to break even with a lifespan as short as 30 years. Only a cottonwood windbreak accumulates enough carbon to break even at a comparison price of \$10.48 Mg^{-1}. A higher carbon price of \$32.38 Mg^{-1} enables a mixed windbreak to break even. Spruce windbreaks (two and four rows) require higher prices to break even. Continuous CRP payments offset a significant portion of windbreak costs and allow more windbreaks to break even and at earlier times.

About 55% of agricultural producers in Northeastern Iowa indicated that there is potential for fee hunting in field shelterbelts and on adjacent lands. However, they think that the potential is either weak or moderate. Almost all producers (95%) currently allow hunting. They believe that hunting is more important in providing intangible benefits such as recreation/enjoyment and better stewardship than tangible ones such as additional income and economic opportunities for the local community. On average, the producers require $22.74 per visit to allow a party of four hunters to access their land to hunt pheasants. The compensation amount is influenced more by producers' attitudes toward hunting than by socioeconomic factors.

CHAPTER 1: GENERAL INTRODUCTION

Introduction

A shelterbelt is composed of one or more rows of trees and/or shrubs. A shelterbelt planted along the edge of an agricultural field or in the interior is designed to provide wind protection to adjacent agricultural crops and is referred to as in-field shelterbelt. In contrast, a farmstead windbreak is planted to protect farmstead buildings, people and livestock by creating a dense wall of vegetation that limits snow deposition, reduces heating and cooling costs, and generally protects farm assets (Baer, 1989). In some regions of the USA, in-field shelterbelts are known also as field windbreaks, whereas in others they are referred as conservation buffers (NRCS, 2004). In this dissertation both names I used interchangeably.

The beneficial roles of in-field shelterbelts and farmstead windbreaks were recognized early by settlers in the Midwestern USA who incorporated them into their farms. They were planted to provide shade in summer, to protect people and livestock against cold winds in winter and to diversify relatively treeless landscapes. Both in-field shelterbelts and windbreaks gained importance during 1930's (dust bowl era) due to their protective role through wind speed reduction. At that time they were planted to reduce soil erosion that was taking place in the Midwestern USA (Baer, 1989). Over time, however, planting of new shelterbelts has decreased (Castonquay and Hansen, 1981). Today a few in-field shelterbelts are being planted, and many existing in-field shelterbelts are in poor condition and aged. As the result, they no longer provide expected benefits (Schaefer et al., 1987).

Scientific literature indicates that in-field shelterbelts, if properly designed, can provide agricultural producers with many valuable benefits including: soil erosion reduction, crop yield enhancement, livestock protection, wildlife habitat, carbon sequestration, snow distribution, energy savings, and aesthetics (Brandle et al., 2004; Vernon et al., 1991; Baer, 1989; Tibke, 1988; Ticknor, 1988; Dearmont et al., 1983). Most of these benefits, except carbon sequestration and aesthetics, occur because of the shelterbelt's ability to reduce wind speed (Heisler and DeWalle, 1988). By modifying the structure of an in-field shelterbelt or its location in relation to the prevailing wind, agricultural producers can attain benefits tailored to their needs. In many cases in-field shelterbelts can be designed to provide several benefits at the same time or provide different benefits, depending on the season of the year.

Because of their ability to provide numerous benefits, in-field shelterbelts have been viewed as a useful practice in mitigating some adverse, unintended effects of agriculture. Agricultural practices have been associated with soil erosion, loss of wildlife habitat, monoculturization of agricultural production, increased use of petroleum based agrichemicals (fertilizers and pesticides, and energy) and decreased diversity of the overall ecosystem. An unintended consequence of this has been increased risk to soil, water, and other environmental assets. Alleviation of negative effects is in the interest of not only the agricultural producers but also society. In-field shelterbelts are technology that can provide desired conservation benefits and if applied correctly, should enhance agricultural production at the same time.

To design a successful in-field shelterbelt, however, it is necessary to understand not only the functioning of in-field shelterbelts but also economic relations between expected shelterbelt benefits (outputs) and associated costs (inputs). There is a compelling need to provide agricultural producers with accurate and comprehensive economic analyses of enhanced crop yield (Jones and Sudmeyer, 2002) and other valuable benefits to help them make better decisions related to establishment of in-field shelterbelts and optimization of all land and human and environmental capital.

Dissertation Organization

This dissertation follows an alternative format approved by the Graduate College of Iowa State University. It includes three separate manuscripts exploring economic effectiveness of in-field shelterbelts at the farm level. The dissertation starts with a general introduction on in-field shelterbelts, their background and role in today's agricultural systems. The general introduction is followed by a literature review on topics explored in three subsequent manuscripts.

The first manuscript included in the dissertation is entitled "Estimates of additional Maize (Zea mays) yields required to offset costs of tree-windbreaks in Midwestern USA" and was published in Agroforestry Systems (Issue 59, pages 11-20, 2003). In this manuscript additional corn yields required to break even are calculated for selected in-field shelterbelt designs. Economic effectiveness of these systems is assessed by comparing required yield increases with those reported in the literature.

The second manuscript is entitled "Economic evaluation of potentials for carbon storage in woody biomass of in-field shelterbelts" and is intended for submission to the Journal of Soil and Water Conservation. The manuscript explores economic feasibility of using in-field shelterbelts to sequester carbon dioxide. The amounts of carbon required to break even at predicted carbon prices are presented for selected shelterbelt designs. Further, prices that would have to be offered to a shelterbelt owner to enable her/him to break even at given carbon accumulation rates are calculated. Finally, the effects of Continuous Conservation Reserve Program (CCRP) payments to farmers on the required carbon amounts and carbon prices are examined.

The third manuscript is entitled "Economic feasibility for enhancing hunting opportunities through planting in-field shelterbelts: farmers' view" and is also intended for submission to the Journal of Soil and Water Conservation. The manuscript examines the opinions of agricultural producers related to benefits and costs of in-field shelterbelts and hunting in them and on adjacent lands. It also analyzes the willingness of producers to provide hunters with access to wildlife habitat at various threshold prices.

The dissertation ends with a general conclusion that summarizes overall research findings and provides recommendations for further research.

Literature Review

In-field shelterbelts and wind speed reduction

In-field shelterbelts gained attention of researchers and agricultural producers primarily because of their protective role through wind speed reduction. An in-field shelterbelt functions as an obstacle that slows wind on the windward and leeward sides (Wang and Takle, 1996a). A portion of the air approaching an in-field shelterbelt is forced to move over the top of the shelterbelt and around it edges (Brandle et al., 2004, Brandle and Finch, 1991) – see Figure 1. Air passing over the top and edges of the in-field shelterbelt is moved forward due to pressure accumulation on the windward side (Brandle and Finch, 1991) and maintains speed greater than open-field wind speed (wind speed over the field that is not protected by an in-field shelterbelt) (Cleugh, 1998). The remaining portion of the air passes through the in-field shelterbelt with a reduced speed (Cleugh, 1998). Although wind speed reductions are observed on both sides of the in-field shelterbelt, on the leeward side they extend over longer distances (Brandle et al., 2004). Wind speed reductions on the windward side can extend up to five times the height of the shelterbelt (Foereid, 2002; Cleugh, 1998), whereas on the leeward side they can be noticeable as far as 30 heights of the shelterbelt (Wray et al., 1997; Wang and Takle, 1996a; Brandle and Finch, 1991). Even larger distances have been reported (Brandle et al., 2004; Heisler and DeWalle, 1988); however, it is believed that the microclimate at such large distances is not affected (Brandle et al., 2004). Wind speed reductions, the distance over which they occur, and the size of sheltered area depend on the shelterbelt structure, which is defined by its density, height, length, orientation and continuity (Nuberg, 1998; Wang and Takle, 1996a; Brandle and Finch, 1991).

Shelterbelt density is a key factor affecting wind speed reductions. Greater wind speed reductions are achieved with in-field shelterbelts that are dense because less air is allowed to pass through the shelterbelt (Brandle and Finch, 1991; Heisler and DeWalle, 1988). However, these reductions occur over shorter distances and the sheltered area is smaller (Wang and Takle, 1996b; McNaughton, 1988). Less dense shelterbelts, on the other hand, provide smaller wind speed reductions, but they occur over longer distances and consequently provide sheltering effect over larger areas (Brandle and Finch, 1991).

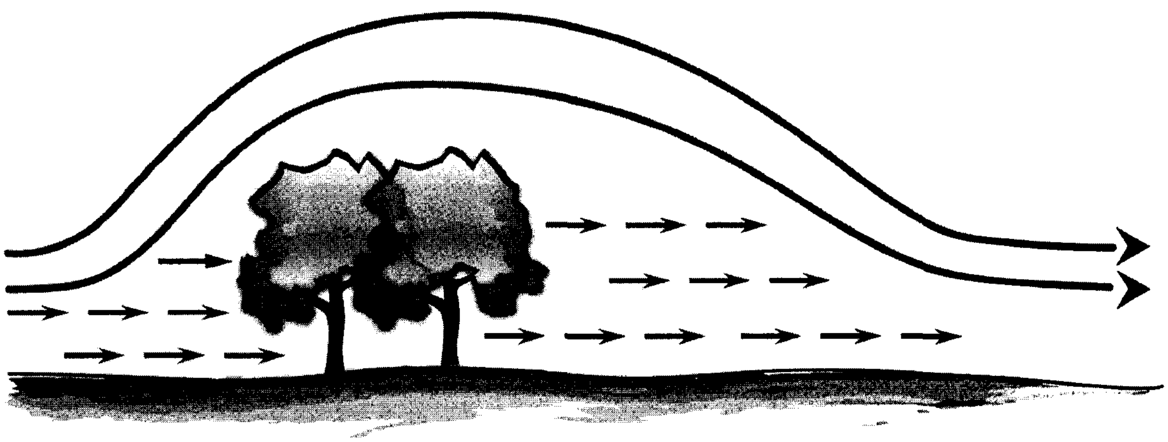
Density of in-field shelterbelts is affected by spacing between the rows of trees and/or shrubs as well as between trees or shrubs within the row. If trees or shrubs are planted close to each other, density is greater. Similarly, a greater number of rows of tress or shrubs results in increased density (Brandle and Finch, 1991). Also, choice of tree and shrub species has great impact on density. For example, conifer shelterbelts have greater density than shelterbelts consisting of hardwoods, especially in winter when hardwoods typically loose their leaves.

Understanding how density affects wind speed is crucial because it allows an agricultural producer to design an in-field shelterbelt that is capable of providing expected benefits. For example, if a landowner intends to protect an adjacent crop field from soil erosion, the density of the in-field shelterbelt should be relatively high, between 40% and 60%. However, if the goal is to ensure an even distribution of snow over the adjacent field, then density should be lower, around 25%-35% (Brandle and Finch, 1991).

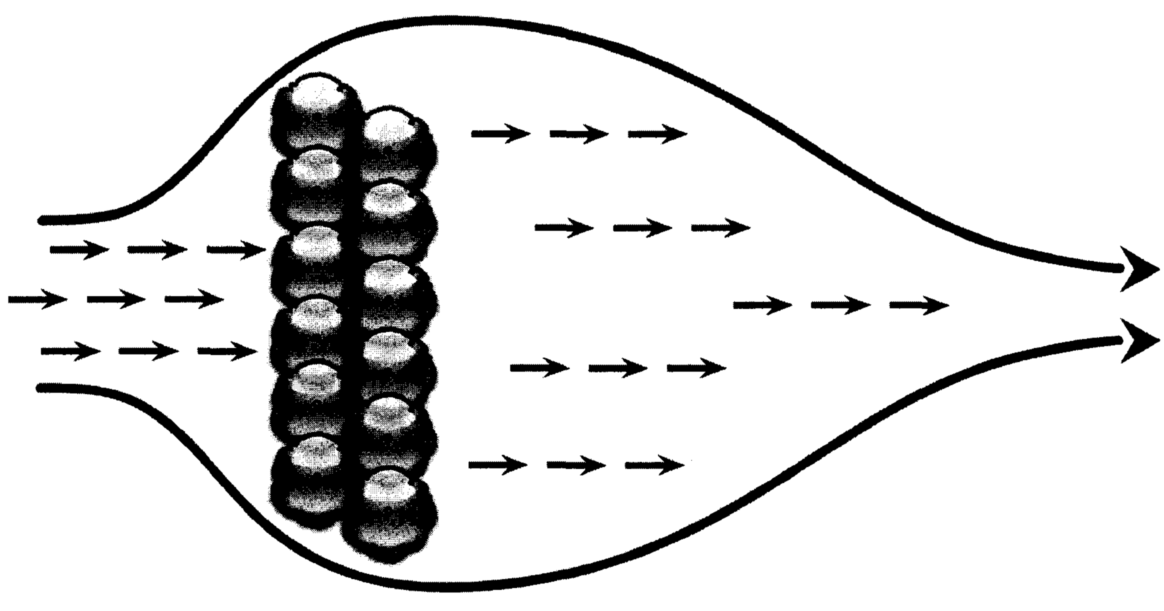
Height of the in-field shelterbelt (H) affects the length of the sheltered zone (Brandle and Finch, 1991; Heisler and DeWalle, 1988). In-field shelterbelts that are taller provide longer protected zones. The length of the sheltered zone increases with time because with age trees grow taller and provide leeward protection over longer distances. Therefore, planting tree species that grow fast and tall is better because they provide sheltering effects sooner and over longer distances.

An in-field shelterbelt will not be fully effective unless it is oriented at a proper angle to the prevailing wind. Orientation of the in-field shelterbelt depends on the expected benefits (Brandle and Finch, 1991). In most cases in-field shelterbelts should be oriented perpendicular to the prevailing wind during the critical period of the year. However, in-field shelterbelts provide various benefits that often occur in different seasons of the year, during which winds change direction. Therefore, it is essential to orient an in-field shelterbelt accordingly to attain expected benefits. For instance, if an agricultural producer intends to protect a crop, then in-field shelterbelts should be located perpendicular to prevailing wind in the growing season when crop is most vulnerable (Brandle and Finch, 1991). However, if the intention is to protect a field against soil erosion, then the in-field shelterbelt should be oriented perpendicular to the prevailing wind during winter and spring when soil is exposed (Brandle and Finch, 1991).

Length of the in-field shelterbelt affects the total size of the sheltered zone (refer to Figure 1). The longer the in-field shelterbelt, the larger the sheltered area. To provide proper sheltering effect, the length of an in-field shelterbelt should be at least 10 times its expected height (Brandle and Finch, 1991). Otherwise, in-field shelterbelt will not provide enough protection due to faster winds on the edges. Also, an in-field shelterbelt needs to be continuous to provide the best sheltering effect. A gap in the trees (for example, because some trees died) provides a tunnel for wind from the windward side. Air will move through this tunnel at increased speed, greater than open-field speeds, resulting in decreased protection on the leeward side (Brandle and Finch, 1991).



Panel a: cross-sectional view



Panel b: plane view

Figure 1. Air flow above and around in-field shelterbelt. Based on Cleugh (1998). Illustrated by Katarzyna Grala

Benefits of in-field shelterbelts

Crop yield increase

An in-field shelterbelt reduces wind speed both on its leeward and windward side and, therefore, provides shelter to adjacent crops. The microclimate within the sheltered zone is altered (Cleugh, 1998; McNaughton, 1988) and crops respond to that change with increased yield (Brandle and Hodges, 2000; Nuberg, 1998; Bird, 1998; Kort, 1988; Bagley, 1964). Crop yield increases due to shelterbelt protection have been documented extensively both in the USA and worldwide – see Kort (1988) for comprehensive summary. Although wind speed reductions are observed on both sides of the in-field shelterbelt, crop yield increases have been measured mostly on the leeward side (Sudmeyer et al., 2002; Frank et al., 1977). Yield increases on that side are significantly greater and extend over larger distances. There are some reports indicating yield increases also on the windward side (Bird, 1998; Baldwin, 1988); however, more research is needed to verify the magnitude of these increases and distance over which they occur. In addition to crop yield enhancement, in-field shelterbelts also protect crops against damage resulting from wind and soil abrasion, which is extremely important in premium crop markets (Cleugh et al., 1998; Baldwin, 1988).

Crop yield increase on the leeward side varies with distance from the in-field shelterbelt (Foereid et al., 2002). In close proximity to the shelterbelt there is a zone of competition (sapping zone) that can extend for 1-2 heights (1-2H) of the in-field shelterbelt (Baldwin, 1988; Bagley, 1964; Stoeckeler, 1963). Within this zone, crops and shelterbelt trees (and shrubs) compete for light, water and nutrients. As a result, crop yield is diminished, and in the area very close to the trees, crop seeds may not germinate. However, as the distance from the in-field shelterbelt increases, competition fades and the crop starts to recover, achieving a normal (unsheltered) yield and then exceeding it (Kuemmel, 2003). The greatest yield increase occurs between 2H and 6H and then it starts to decrease as wind speed increases. The zone of increased crop yield can extend up to 13-25H. After that, crop yield is the same as on unsheltered field (Qi et al., 2001; Bird, 1998; Stoeckeler, 1963; Bates, 1944).

Reported crop yield increases vary greatly, depending on geographical location, weather conditions, soil quality, shelterbelt design, and crop type. For example, Kort (1988) showed that crop yield increases range from a loss of 8% to a gain of 203% based on geographical location and crop type. Frank et al. (1977) report wheat yield increases of 22% and 19% for irrigated and non-irrigated sheltered fields, respectively. Brandle et al. (1984) conducted an experiment in which a system of in-field shelterbelts protected wheat field plots. Observed yield increased on average to 15%. Bagley (1964) recorded tomato yield increases as high as 44%.

The great diversity of growing conditions as well as differences in duration of measurements makes comparison of enhanced crop yields very challenging. Experimental designs in many cases differed significantly and, therefore, extra caution should be exercised when comparing them and making economic recommendations. Also, yield measurements were usually taken over relatively short periods of time in comparison to lifespan of in-field shelterbelts. Reported yields might be affected by unusual annual weather conditions and may not reflect typical achievable yield increases (or losses). As a result, economic analyses of enhanced crop yield might under or overestimate potential returns available to agricultural producers.

Carbon sequestration

There has been an increasing concern with the negative effects of global warming and potential ways to mitigate them. Global warming is believed to be caused by so-called greenhouse gases (GHGs) of which carbon dioxide (CO_2) is the most abundant (IPCC, 2001; Wigley, 2001). The CO_2 is released due to both natural and anthropogenic processes. Elevated concentration of CO_2 in the atmosphere is attributed mainly to burning fossil fuels, such as coal, oil, and natural gas, and deforestation (IPCC, 2001). As CO_2 is the most significant contributor to global warming potential (GWP), efforts to alleviate negative effects of global warming have consequently focused on decreasing its concentration in the atmosphere.

Decrease of CO_2 presence in the atmosphere can be achieved in two ways: through reduction of CO_2 emissions and through expansion of carbon sinks. Trees gained considerable attention in the Kyoto Protocol (1997) due to their ability to absorb significant amounts of CO_2 during photosynthesis and lock carbon (C) up for long periods (Sampson and Sedjo, 1997) and relative cost effectiveness in comparison to other methods (Plantinga et al., 1999). Absorption of CO_2 from the atmosphere can be increased via additional tree plantings, decreased release of carbon back to the atmosphere through various forest management practices and decreased deforestation, and conversion of carbon into long-life wood products (Sampson and Sedjo, 1997).

Many studies have been conducted to estimate the cost of carbon sequestration in woody biomass. Most studies focus on carbon storage through large-scale expansion of forested areas. Studies show significant variations in the cost of storing additional amounts of carbon. For example, Plantinga et al. (1999) conducted an econometric analysis to establish marginal costs of sequestering carbon through afforestation in Maine, South Carolina, and Wisconsin, USA. Their results show that marginal cost can be as high as $109 per metric ton depending on scenario and state. They point out, however, that sequestering carbon via afforestation seems to be a cost-effective alternative. Stavins (1999) employs an econometric model of land use to simulate carbon sequestration to derive marginal and average costs of carbon sequestration on a regional scale for various carbon sequestration levels. Marginal cost can reach $132 per metric ton, whereas average cost can elevate to $602 per metric ton depending annual carbon sequestration level. Adams et al. (1999) also calculate the cost of storing carbon in forests to attain specific target carbon sequestration levels for the US. The costs represent welfare losses in the market for forest and agricultural products. In their model, they allow both forest management actions and forest area to vary. Reported marginal costs vary from $5 to $22 per metric ton per year, depending on desired sequestration level. Huang and Konrad (2001), on the other hand, take a different approach. They use soil expectation value (SEV) and mean annual increment (MAI) to calculate economically and biologically optimal forest rotations, and based on that, compute required compensations for carbon storage. Their costs range from $0.74 to $181.27 per metric ton depending on the forest management alternative. Parks and Hardie (1995) simulate a national carbon sequestration program for storing carbon in forests planted on marginal agricultural lands where the lands are selected based on least cost per ton of carbon. Calculated costs vary from $69 to $200 per metric ton.

Agroforestry practices have been recognized as a significant carbon sink that enables storage of additional amounts of carbon on agricultural lands and still allow crop production (Montagnini and Nair, 2004; Kort and Turnock, 1997). In the temperate region of the USA, in-field shelterbelts are one of the major agroforestry practices. Although they maintain relatively low tree stocking and cover small areas in comparison to adjacent agricultural fields, they have been indicated as an efficient land use to sequester CO_2 (Brandle et al., 1992b). Brandle et al. (1992b) also emphasize that in-field shelterbelts, in addition to carbon sequestration, provide other valuable conservational benefits such as soil erosion reduction, crop yield enhancement, wildlife habitat and energy savings. The energy savings lead in turn to decreased emissions of CO_2. Kort and Turnock (1999) report that in-field shelterbelts constitute a considerable reservoir of carbon in the prairie. According to their estimates such in-field shelterbelts can store from 11 to 105 metric tons of carbon per kilometer of the shelterbelt. Reported amounts of carbon vary with species, spacing, and soil type. In another study, Kort and Turnock (1998) estimated annual and total amounts of carbon accumulated in biomass of selected species of trees and shrubs planted in in-field shelterbelts. Their results allow for selecting species and shelterbelt designs that will maximize carbon sequestration.

Storing carbon within in-field shelterbelts presents landowners with new opportunities to generate additional income. Although carbon currently is not formally traded in the US, voluntary programs indicate growing interest in carbon trading – see Chicago Climate Exchange that is a pilot trading program for emissions sources (greenhouse gases) and offset projects in the USA, Canada and Mexico (CCX 2004). Economic analyses are needed to assess effectiveness of in-field shelterbelts in storing carbon and identify shelterbelt designs that will maximize shelterbelts benefits.

Wildlife habitat

In-field shelterbelts have been known to attract various species of game and non-game wildlife (Johnson et al., 1994; Johnson and Beck, 1988; Schwilling, 1982; Stormer and Valentine, 1981). In agricultural landscapes they function as islands of woody vegetation (Girard et al., 1983; Stormer and Valentine 1981), in which wildlife seek food, nesting and resting places, shelter against predators and adverse weather conditions, and to travel (Johnson and Beck, 1988; Hintz, 1984; Stormer and Valentine, 1981).

Importance of in-field shelterbelts in providing habitat for wildlife is particularly high in regions where agriculture is intensive (Hays, 1990; Capel, 1988), especially to tree-dependent species (Ronneberg, 1992). In such regions, in-field shelterbelts increase diversity of both fauna and flora as well as they improve aesthetics of the area (Ronneberg, 1992).

Researchers report a large variety of birds and animals benefiting greatly from the presence of in-field shelterbelts. Johnson et al. (1994) report that in-field shelterbelts are often used by various song birds, woodpeckers, ring-necked pheasants (*Phasianus colchicus*), mourning doves (*Zenaida macroura*), and bobwhite quail (*Colinus virginianus*). They also indicate common animals, such as cottontails (*Sylvilagus* spp.), squirrels (*Sciurus* spp.), and white-tailed deer (*Odocoileus virginianus*). Johnson and Beck (1988) report various studies on shelterbelt use by birds and animals. According to them, there are 108 species of birds and 28 species of animals utilizing in-field shelterbelts in various ways. Researchers report that presence of in-field shelterbelt enabled some animals and birds to extend their range (Stormer and Valentine, 1981; Hintz 1984). It should be emphasized that reported species benefiting from in-field shelterbelts vary, depending on the region, and that for many wildlife species the in-field shelterbelts fulfill only part of their habitat needs (Hays, 1990).

It is clear that in-field shelterbelts are crucial for enhancing and preserving wildlife habitat in regions where trees are sparse. Unfortunately, in-field shelterbelts that were planted in the past (1930's and 1940's) have deteriorated (Hays, 1990) and many have, therefore, been removed (Baltensperger, 1987; Sorenson and Marotz, 1977). Consequently, new planting efforts are needed to ensure that wildlife habitat is sustained (Hays, 1990).

Landowners do not perceive wildlife habitat as particularly important. According to a study conducted in Nebraska by Dearmont et al. (1983), only 6% of producers thought that wildlife habitat was the most important reason for planting in-field shelterbelt. The general belief is that providing wildlife habitat in many cases does not offer a landowner any financial reward. Some landowners tend to think that there is no potential for generating additional income because of limited demand for hunting in in-field shelterbelts and on lands adjacent to them. Others believe in free access to wildlife habitat, especially in states where hunting on private lands has been traditionally free. Accordingly, other benefits of in-field shelterbelts are perceived to be more important, especially increasing the value of the agricultural crop protected by the trees (May, 1978).

In-field shelterbelts do provide agricultural producers with an opportunity to generate additional income by providing hunters with access to wildlife habitat in exchange for a fee. Smith et al. (1992) indicate that "fee and lease hunting" gains in importance as landowners see the opportunity for diversifying their income due to unfavorable crop prices. Hunters also are increasingly interested in fee and lease hunting as they see this as an opportunity to secure an access to quality wildlife habitat, which might not be available to them otherwise

(Smith et al., 1992). It is predicted that demand for hunting will be continuously increasing (Wright and Kaiser, 1986), and it seems that the importance of in-field shelterbelts in providing wildlife habitat for hunting will increase too, especially in states with limited tree coverage.

Despite extensive research on the beneficial role of in-field shelterbelts in enhancing wildlife habitat, hunting opportunities on lands adjacent to them have been examined only to a limited extent. Findings on hunting in Kansas by Cable and Cook (1990) indicate that hunters often use in-field shelterbelts for hunting and about 80% of hunters would use them more if there were more in-field shelterbelts available. The value of hunting associated with in-field shelterbelts can be significant. Cook and Cable (1990) estimated that the net economic value of in-field shelterbelts to hunters in Kansas was $21.5 million in 1990, and expenditures related to this hunting amounted to another $30.5 million. As in-field shelterbelts increase hunting success, Johnson and Beck (1988) suggest that there is a potential for generating additional income from granting hunting privileges on lands associated with them.

Almost any in-field shelterbelt can provide some type of wildlife habitat. However, only those that are designed to optimize wildlife benefits will provide suitable habitat and be attractive to hunters. Landowners should take this into account as hunters are willing to pay premium prices for an access to wildlife habitat that provides better hunting opportunities (experience and success) (Cook and Cable, 1990). In-field shelterbelts, if properly designed, can provide a landowner not only with wildlife habitat, but also other valuable benefits, such soil erosion reduction, crop yield and quality enhancement, snow distribution and aesthetics.

Benefits and costs associated with in-field shelterbelts

Scientific literature indicates that in-field shelterbelts, if properly designed, provide landowners with many valuable benefits, including reduction of soil erosion, crop yield increase, livestock protection, wildlife habitat, carbon sequestration, snow distribution, energy savings, and aesthetics (Brandle et al., 2004; Vernon et al., 1991; Baer, 1989; Dearmont et al., 1983). Some of these benefits, such as increased crop yield, can provide producers with additional market income and are relatively easy to quantify, whereas others, such as soil erosion reduction, provide significant cost savings, but are difficult to quantify (Brandle et al., 2004).

However, besides improving the economic efficiency of crop and livestock production, in-field shelterbelts also provide important environmental amenities for agricultural producers and society (Johnson et al., 1994; Brandle et al., 1992a). These benefits include wildlife habitat, soil erosion reduction, carbon sequestration, and aesthetics. To accrue these benefits requires a long-term commitment of land, explicit design consideration and financial resources. There is strong need to evaluate the economic efficacy of in-field shelterbelt considering multiple benefits.

Many researchers indicate that in-field shelterbelt benefits more than compensate for their costs (Vernon et al., 1991). However, despite a continuous effort from both government and non-government organizations to increase shelterbelt plantings in the USA, the realized area of new plantings is far below the goal of 1.5 million hectares (to provide crop protection and wind erosion reduction) (Brandle et al., 1992b). Even though these organizations provide significant educational, technical and financial assistance, agricultural producers are rather reluctant to plant in-field shelterbelts. It seems that there are several reasons contributing to this situation.

Most of the in-field shelterbelt benefits are not easily quantifiable in monetary terms, and therefore, they are not accounted for in typical farm financial analyses. To many agricultural producers, the benefits are not obvious, and they question whether the benefits really outweigh the costs (Dearmont, 1983). This opinion is further emphasized by the fact that shelterbelt benefits are not readily obtainable. It takes 10-15 years before the first benefits accrue to the landowner and even more time is required for the benefits to offset the costs (Brandle et al., 1992a, Brandle et al., 1984). This is significantly longer than the annual time frame on which agricultural producers operate. This contributes to increased uncertainty, in comparison to annual crops, related to shelterbelt survival and performance over time, which further discourages agricultural producers, as land has to be committed for a relatively long time and cannot be used for other purposes. Consequently, managerial decisions span significantly longer periods of time. In the case of crop production, if a loss occurs, the decision can be corrected within one year. In the case of an in-field shelterbelt, however, more time is required to make a judgment if it does not perform as expected. Thus, losses accumulated over time before any decision is made can be significantly greater. Also, some agricultural producers may consider an in-field shelterbelt to be a liability due to increased costs of future removal or regeneration.

In-field shelterbelts not only take land out of crop production but also compete with adjacent crops for water, light, and nutrients. They often interfere with farm operations as they need to meet specific location requirements to function effectively and provide expected benefits (Sturrock, 1988). Consequently, many producers do not perceive shelterbelts as particularly attractive investments and adoption of shelterbelt technology has been less than satisfactory (Marsh, 1999; Sturrock, 1988)

The issues mentioned above could suggest that in-field shelterbelts are economically infeasible. However, researchers and field practitioners suggest otherwise. Research on in-field shelterbelts has progressed significantly, offering agricultural producers a new technology in designing in-field shelterbelt systems. This technology allows the producers to adopt systems that fit better into their farm operations and are economically more effective. Economic viability is crucial in promoting in-field shelterbelts, as agricultural producers are unlikely to adopt practices that will result in decreased returns from their land.

Current shelterbelt systems are designed not only to decrease trade-offs between shelterbelts and agricultural production but also to enhance value of the later. In the past, many systems were designed with a limited knowledge of shelterbelt functioning and their long-term interaction with adjacent crops. In-field shelterbelts planted in the past often occupied larger areas than current in-field shelterbelt systems. While those designs provided other significant benefits, such as wildlife habitat, in terms of crop production they were often economically inefficient because occupied areas were unnecessarily large. Now, researchers know how to design in-field shelterbelt systems that occupy less land and still provide the same wind speed reductions (Takle E.S., pers. comm. 2003).

Despite extensive research on biological and functional aspects of in-field shelterbelts, economic relations between various in-field shelterbelt benefits and associated costs are still not fully explored. Most economic analyses to date have focused primarily on the value of crop yield increase on adjacent agricultural fields. This seemed to be an obvious approach because increased crop production provided agricultural producers with additional income and could be easily compared with costs of committed land and lost crop production associated with it. However, in-field shelterbelts also provide other valuable benefits. These benefits can often be provided at the same time without diminishing primary benefits and can be a source of additional income to agricultural producers (Vernon, 1991). A comprehensive economic analysis of crop yield increase as well as other benefits, and associated costs is needed to properly assess the economic effectiveness of in-field shelterbelts.

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CHAPTER 2: ESTIMATES OF ADDITIONAL MAIZE (*ZEA MAYS*) YIELDS REQUIRED TO OFFSET COSTS OF TREE-WINDBREAKS IN MIDWESTERN USA

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Key words: break-even, field windbreak, leeward protected zone, present value

Abstract

Field windbreaks can increase crop yield within a protected zone. However, they also take land out of crop production and compete with adjacent crops. Although the beneficial aspects are generally recognized, the question arises whether the windbreak will increase crop revenue enough to offset costs over time. Achieving additional yields to offset windbreak costs might be a sufficient incentive for a producer to plant a windbreak. Additional maize (*Zea mays*) yields necessary to break-even with costs are calculated for four typical Midwestern US field windbreaks: poplar (*Populus* spp.), mixed tree/shrubs (*Populus* spp., *Acer saccharinum L.*/*Physocarpus* spp., *Viburnum* spp., *Cornus* spp.), and two and four-row spruce (*Picea* spp.) windbreaks. Five lifespans, two management and two cost scenarios, and

three protected zone widths to account for changing sheltering effects are evaluated. Greatest additional yields are for a 4-row spruce windbreak with intensive management at high cost and a 10-year lifespan: 15.38 Mg ha^{-1} yr^{-1} within 6H, 7.69 Mg ha^{-1} yr^{-1} within 12H and 6.15 Mg ha^{-1} yr^{-1} within 15H. If a 50-year lifespan is implemented, the additional yields are about 11% of those in 10-year lifespan. Smallest additional yields are for a mixed tree/shrubs windbreak with extensive management at low cost and a 50-year lifespan: 0.56 Mg ha^{-1} yr^{-1}, 0.28 Mg ha^{-1} yr^{-1} and 0.22 Mg ha^{-1} yr^{-1}, respectively. The mixed windbreak is likely to have actual maize yield increases comparable to the required ACY_{UA} to break even as long as the lifespan is 30 year or longer with a minimum protected zone of 12H.

Introduction

Field windbreaks provide a wide range of benefits including wind speed reduction, soil erosion control, yield increase and biodiversity enhancement (Johnson et al. 1994; Baer 1989). For this reason, windbreaks not only increase crop production on farmland but also improve its sustainability (Brandle et al. 1992). Although windbreak benefits are recognized by producers, they are reluctant to plant windbreaks because of concerns for land taken out of production and diminished crop harvest (Kort 1988). Moreover, as many of the windbreak benefits do not provide obvious direct financial revenues to the producer, they are not accounted for in typical farm analysis and so there is little incentive beyond enhanced crop yields for producers to establish windbreaks. Furthermore, most of windbreak costs are incurred initially, whereas yield benefits are delayed in time. This creates additional discouragement, as a relatively long time period might be needed before recaptured yield benefits will offset windbreak costs.

Many researchers report that windbreaks do provide a significant crop yield increase that could provide incremental revenues enough to offset windbreak costs. Yield increase can be as high as 200% depending on geographical location, weather and distance from windbreak (Kort 1988). Baer (1989) presents increased yields for various crops up to 110%. GAO (1975) describes maize (*Zea mays*) yield increase as high as 19% within the protected zone from two to ten windbreak heights (H). Further, Brandle et al. (1984) provide evidence that wheat (*Triticum aestivum*) yield increase can be as high as 50%. It is necessary to stress that yield increases vary significantly and depend on several factors including weather conditions and windbreak structure that has a direct impact on a wind speed (Brandle et al. 2000; Kort 1988; Brandle et al. 1992; Brandle et al. 1984). Further, yield increase is not uniform across the field; rather it depends on the distance from a windbreak (GAO 1975; McMartin et al. 1974; Stoeckeler 1963).

Economic analyses of yield increase are relatively few and limited to short time periods that do not take into account the entire effective lifespan of a windbreak. Therefore, such analyses may not reveal the full value of the yield increase and associated costs. Nevertheless, studies conducted so far reveal interesting results and give some perspective for future analysis. Brandle et al. (1984) conducted a benefit-cost analysis and used payback period and Net Present Value (NPV) as economic criteria to evaluate a windbreak project. In another study, Brandle et al. (1992) evaluated selected windbreak systems with NPV and various discount rates. Powell (1985) evaluated windbreaks in terms of cost savings. In contrast, McMartin et al. (1974) compared the value of the yield with windbreak protection to the value of the crop with no protection, but over a short time period. Similarly, Stoeckeler (1963) compared yield gain to the base yield of an unprotected field.

Here, we calculate additional maize yields that would allow a maize producer to break even for a given windbreak scenario (defined by windbreak species, lifespan, management intensity and cost option). We assume that to provide sufficient incentive for a producer to plant a windbreak, the expected benefits of additional maize yield must at least equal the costs of establishing and managing the windbreak. Therefore, we calculate additional maize yields that are required to offset costs (to break even) for selected windbreaks and examine if there is evidence in the literature that such yield increases can be achieved. If observed yield increases are greater than those needed to break even, a producer will be able to generate revenue greater than costs and will have a stronger incentive to plant a windbreak. Further, we establish the time needed to attain additional crop yields needed to break even, and examine the influence of protected zone length on these yields.

Materials and Methods

Break-even model

In the model, we calculate additional maize yields that are assumed to occur due to the windbreak protection and are required to break even (see Rose 1977 for a similar model applied to woody plantations for biofuels). These yields are obtained within the protected zone on the leeward side of the windbreak (see Figure 1) and are above the regular yield that is obtained if the field is not sheltered by a windbreak. Figure 1 shows that there is yield loss in the area adjacent to the windbreak due to competition (*YL*). Further, one can see that additional crop yield (*ACY*) starts to increase in relatively close proximity to the windbreak, then it reaches its maximum and starts to decline to reach the level of unprotected yield marked by a dashed line (*UY*).

Our model assumes that a windbreak is oriented north-south with a maize field on the east. We recognize that during the year wind approaches a windbreak from various directions creating a sheltered area of irregular sizes. Thus, to simplify the model and to account for the greatest sheltering effect we further assume that the prevailing wind is from the west, perpendicular to the windbreak (Brandle et al. 2000). Further, we assume that there are three lengths of the leeward protected zone within which there is measurable yield increase. The width of the protected zone equals the length of the windbreak (perpendicular to wind direction), whereas its length is expressed as multiples of the windbreak height (H) and runs parallel to wind direction. For example, if the total height of the windbreak is 9 m and the length of the protected zone is 12H, this means that the length equals 108 m. While the length expressed in terms of windbreak heights is always the same, the actual distance will increase as trees within the windbreak grow taller. This process continues until the windbreak species reach maturity. In the most pessimistic zone, the length is 6H, whereas in the most optimistic zone it is 15H (McMartin et al. 1974). For the "most likely" scenario, the length of the leeward protected zone is 12H (GAO 1975; Stoeckeler 1962).

To simplify a complex biological system and for lack of data on early height growth and effects on crop yield, we assume that there is no yield response during the first five years after windbreak establishment and that the sheltering effect occurs from year six onward (J.

R. Brandle, pers. comm. 2001). We estimate mean protected area by summing sheltered areas from year six to the end of windbreak lifespan and dividing the sum by lifespan (years).

For a windbreak to be a viable economic investment, the expected benefits have to at least offset the costs of establishing and managing such windbreak. Therefore, when accounting for maize yield only, the additional yield needs to generate financial revenue large enough to offset windbreak costs. Additional maize yields necessary to break even are calculated as annual additional yields per protected hectare (see equation below). For detailed discussion on development of this equation refer to appendix.

$$ACY_{UA} = \frac{PV_C \times M}{\overline{P} \times A}$$

where:

ACY_{UA} = annual required additional crop yield accumulated over the unit of sheltered area (Mg^{-1} ha^{-1} yr^{-1})

PV_C = Present Value of windbreak establishment and maintenance cost accumulated over windbreak lifespan.

M = Multiplier (used to account for value change)

$\overline{P}$ = fixed maize price of \$68.11 Mg^{-1} (\$1.73 bu^{-1}) (IDALS, 2001)

A = area of sheltered zone (ha) Further, The ACY_{UA} represents additional crop yield that would have to be obtained every year during windbreak lifespan in order to offset windbreak costs. This break-even model can be applied to any type of crop being cultivated on field with windbreak protection.

Windbreak scenarios

We include four windbreak designs in our model based on types found in Midwestern United States. There is a fixed width to all designs equal to 1610 m. Length of the protected zone is based on height of the tallest windbreak row and was evaluated using height-age curves for respective species (P. H. Wray, pers. comm. 2001; Wray and Thomson 1987; Johnston 1977). Each windbreak is evaluated at five lifespans: 10, 20, 30, 40 and 50 years. The short lifespan (10 years) is rather typical for private investment, whereas the long lifespan represents the biological potential of a windbreak. Further, each windbreak is evaluated at two management scenarios: extensive and intensive. In the extensive scenario, a producer removes the windbreak as soon as it reaches its maturity, whereas in the intensive scenario it is assumed that the producer replants the windbreak in order to have protection in the future. Each management scenario is evaluated at two cost options: low and high. Both options reflect variation in windbreak costs, mostly in terms of seedlings and custom operation costs (see Table 1). In total, 240 windbreak scenarios are considered.

Design 1 Poplar (4 rows)

Poplar trees (*Populus* spp.) are planted in four rows in spacing 3.35 m between rows and 1.52 m within a row. The windbreak is 12.19 m wide and occupies an area of 1.96 ha. There are 2691 trees planted per ha (5280 trees in total).

Design 2 Mixed Species (3 rows)

A mixed windbreak is planted in three rows: one row of poplar (*Populus* spp.), one of silver maple (*Acer saccharinum L.*) and one row of mixed shrubs such as ninebark (*Physocarpus* spp.), highbush cranberry (*Viburnum* spp.) and dogwood (*Cornus* spp.). The distance between tree rows is 3.35 m and 1.52 m between a tree and shrub row. Both trees and shrubs are planted at a spacing of 1.52 m within a row. The width of the windbreak is 7.31 m and its total area is 1.18 ha. There are 1794 trees and 897 shrubs per ha planted in this windbreak. This design is presented in Figure 2.

Design 3 Spruce (2 rows)

Spruce (*Picea* spp.) is planted in two rows in spacing of 4.57 m between rows and 3.05 m within a row. The width of the windbreak is 9.14 m and the total area of the land strip occupied by windbreak is 1.47 ha. There are 717 trees planted per ha (1056 in total).

Design 4 Spruce (4 rows)

Spruce (*Picea* spp.) is planted in four rows in spacing of 3.05 m between rows and within the row. The width of this windbreak is 12.19 m, whereas the total area is 1.96 ha. About 1077 trees per ha are planted to this windbreak (2112 in total).

Results

Calculating Present Value of windbreak costs – PV_C

We used constant year 2000 costs and management actions typical for windbreaks planted in Midwestern United States. Typical costs incurred by planting a mixed windbreak with extensive management for a 50-year lifespan are presented in Table 1.

As costs are incurred in various times, they have to be discounted properly to the present time to be able to compare various windbreak scenarios. All the costs were discounted using a 5% real alternative rate of return for each windbreak design at both scenarios and at both cost options and five lifespans. The Present Value cost (PV_C) values (US\$ ha^{-1}) are presented in Figure 3.

Figure 3 shows that PV_C at 5% varies considerably across lifespans, but also across different windbreak scenarios. As expected the PV_C increases with lifespan. The increase is greatest between 10-year and 20-year lifespan and decreases afterwards with every decade. It is evident that 10-year lifespan is the least costly across all management scenarios. However, if the lifespan is extended, the increase in PV_C is less with each future decade. The PV_C increases with lifespan in all scenarios due to cost accumulation over time.

A 2-row spruce windbreak, mixed and poplar windbreak, all with extensive management at low cost have the lowest PV_C across lifespans. Similarly, the mixed windbreak, the spruce planted in four rows and the poplar windbreak, all with intensive management at high cost, are the most costly scenarios across all lifespans. However, in other windbreak scenarios, ranking is more complicated. For example, if we compare spruce planted in four rows in intensive management at low cost (\$10,000 ha^{-1}) against mixed windbreak in extensive management at high cost (\$9,200 ha^{-1}) for a 10-year lifespan, it is clear that the mixed windbreak is less costly. However, the mixed windbreak maintains relatively the same increase in PV_C over each decade, while for spruce this increase is much smaller with each decade. The result is that with a 30-year lifespan, the mixed windbreak becomes more costly and continues to be more costly until 50 years. Similar patterns are observed in a case of other windbreak scenarios (Figure 3).

Analysis of PV_C for the windbreak scenarios, while providing some interesting patterns, does not provide the necessary results on windbreak efficiency, as do the additional maize yields required to offset the PV_C.

Calculating Additional Maize Yields - ACY_{UA}

Additional maize yields (ACY_{UA}) required to break even were calculated using a fixed maize price of \$68.11 Mg^{-1} (\$1.73 bu^{-1}), which is a twelve-month average for year 2000

(IDALS 2001). We assumed a maize yield of 8.91 Mg ha^{-1} if there is no windbreak protection, which is based on average yield for Iowa, Nebraska and Illinois for years 1998, 1999 and 2000 (NASS 2001). A mixed windbreak with extensive management scenario and low cost is superior to other windbreaks because it requires the least ACY_{UA} across three lengths of the leeward protected zone (Table 2). The additional maize yields necessary to break even are the lowest if the 50-year lifespan is implemented and if the protected zone is 15H. For 10-year lifespan for a mixed windbreak (extensive management and low cost), the ACY_{UA} is 4.39 Mg ha^{-1} yr^{-1} with 6H protected zone, 2.20 Mg ha^{-1} yr^{-1} with 12H, and 1.76 Mg ha^{-1} yr^{-1} with 15H. In contrast, for the 50-year lifespan the ACY_{UA} are 0.56 Mg ha^{-1} yr^{-1}, 0.28 Mg ha^{-1} yr^{-1} and 0.22 Mg ha^{-1} yr^{-1}, respectively (Table 2). These additional maize yields are about 13% of the ones in 10-year lifespan. Further, for both the 10 and 50-year lifespans, the additional yields within 15H are nearly 40% of the ones within 6H. When comparing ACY_{UA} with observed sheltered maize yields as presented by Stoeckeler (1962) of 0.42 Mg ha^{-1}, it is clear that for this mixed windbreak with 30, 40, 50-year lifespans and 12H and 15H protected zones, produce ACY_{UA} that are less than or equal to those observed.

The additional maize yields required to attain break-even level are greatest for spruce planted in four rows in intensive scenario at high cost with a 10-year lifespan (Table 2). This spruce windbreak requires additional maize yields of over 300% more than the mixed windbreak and are much greater than the 0.42 Mg ha^{-1} reported by Stoeckeler (1962). However, using observed 10% to 15% maize yield increases: 0.89 Mg ha^{-1} to 1.34 Mg ha^{-1} using 8.91 Mg ha^{-1} base, the spruce (4 rows) windbreak with 40 and 50-year lifespan, and a 15H protected zone produce ACY_{UA} that are less than those reported (see Kort 1988 for summary on reported crop yield increases).

Three general trends emerge. First, as the lifespan of the windbreak lengthens, the additional yields needed to break even decrease significantly. This holds for all windbreak scenarios. The greatest decrease is observed when the lifespan is extended from 10 years to 20 years and next greatest decrease is from 20 years to 30 years. If the lifespan is extended further, the decrease in additional yields is still observed but at decreasing rates. Second, the width of the protected zone has a great impact on additional maize yields. The wider the protected zone, the smaller the additional maize yield that is required to break even across all windbreak scenarios. The ranking of windbreak scenarios does not change. For instance, if the windbreak scenario is ranked as requiring the lowest additional maize yield within a 6H protected zone, it will also require the lowest additional yield within the 12H and 15H protected zones (Table 2). Third, the mixed and poplar windbreaks with 12H protected zone or better and lifespans ≥ 30 years are more likely to have ACY_{UA} that are comparable to those reported for sheltered maize yields.

Discussion and Conclusions

This analysis reveals that additional maize yields necessary to break even vary significantly across windbreak scenarios, lifespans and lengths of the protected zone. The best windbreak scenario is a mixed windbreak planted with extensive management at low costs for a 50-year lifespan - it requires the smallest additional maize yields to break even. In contrast, a 4-row spruce windbreak planted with intensive management at high cost for a 10-year lifespan is the worst scenario because it requires the greatest additional maize yields.

Thinking only of benefits from additional crop production, longer lifespans are better because windbreaks grow taller and provide protection over the larger area. Thus, costs accumulated during the windbreak lifespan are spread over a larger protected area and per hectare additional maize yields needed to offset windbreak costs are smaller. Moreover, an opportunity cost of extending a windbreak lifespan is relatively small, as extra costs constitute only a fraction of initial costs. Therefore, windbreaks with longer lifespan and larger protected zone are more likely to attain required additional yields.

High initial costs discourage many producers from planting windbreaks. However, our calculations show that cost should not be used as the only criterion for evaluating economical effectiveness of a windbreak. A low cost windbreak does not guarantee a low additional maize yield needed to break even. For example, a spruce windbreak planted in two rows with extensive management and low costs is identified as the least costly windbreak scenario. However, it does not produce the smallest ACY_{UA}. In fact, this scenario is ranked seventh in terms of minimum additional yield of maize at a 50-year lifespan. Similarly, a mixed windbreak planted in intensive management at high cost is classified as the most costly scenario. However, it does not require the greatest additional maize yield, but is ranked fourth (at a 50-year lifespan). The reason for these differences is that the tree species in each windbreak are assumed to grow at different rates. So, for the mixed windbreak where the height is defined by tallest row of poplar, the fast growth offsets the high PV_C. It provides a longer protected zone and, therefore, smaller additional maize yields are needed to break even. Fast growing trees will start providing crop protection sooner allowing for recovering the windbreak costs with shorter lifespan.

The ACY_{UA} for some scenarios are lower than those reported for maize. If the actual additional maize yield from windbreak protection is 4.7% (0.42 Mg^{-1} ha^{-1}) then only 9% of the 240 windbreak-protected zone-lifespan combinations in Table 2 are comparable. But if the actual additional maize yield is 10%, then 40% of combinations are comparable. Clearly, if crop response to sheltering effect is poor, the more time is needed to accumulate enough of additional crop to offset windbreak costs. Further, for some windbreak designs it will be impossible to achieve such yields. Alternatively, if crop responds well to sheltering effect, it will be possible to break even with shorter lifespans and with more windbreak designs and scenarios. Differences in additional maize yields for 30, 40 and 50-year (12H and 15H) lifespan are relatively small, so a producer has more flexibility in committing land to windbreak use.

The real discount rate, market price and cost share have a significant influence on the level of minimum additional maize yields necessary to break even. In this model, a larger real discount rate will cause ACY_{UA} to increase. Increases in market price increase additional crop income (*ACI*), thus reducing the required additional maize yields. Any level of cost share from governmental or non-governmental sources will decrease the level of required additional yields.

Further analysis is needed to account for potential yield increase on the windward side of the windbreak. Windward yield increases, if greater than crop loss due to the windbreak competition, will decrease required additional yields as well. Finally, the analysis presented above only accounted for the yield increase of maize. Many other benefits exist such as carbon sequestration, soil erosion control, hunting opportunities, biodiversity enhancement, and aesthetics. If these benefits are accounted for in an analysis, additional yields required to break even will be lower.

Appendix

To determine the required additional maize yields at which a producer breaks even with the windbreak establishment and maintenance costs, Present Value of additional crop income (PV_{ACI}) has to equal Present Value windbreak costs (PV_C). Equation 1 presents the general form of the break-even model.

$$PV_{ACI} = PV_C \tag{1}$$

PV_{ACI} includes income from additional crop yields (ACY) obtained during a windbreak lifespan and discounted to present time (Equation 2).

$$PV_{ACI} = \sum_{t=0}^{n} \frac{ACI_t}{(1+i)^t} \tag{2}$$

where:

PV_{ACI} = sum of discounted additional crop incomes obtained during the windbreak lifespan

ACI_t = additional crop income obtained in particular year (assumed due to sheltering effect)

t = year, at which yield income was obtained; t = 0, 1, 2 … n

i = real interest rate

n = windbreak lifespan (10, 20, 30, 40 or 50 years)

Similarly, PV_C includes all the costs of establishing and managing the windbreak, including land rent.

The accumulated monetary value of additional yields of maize (additional crop income) must balance with the windbreak costs in order to break even. Consequently, the stream of discounted additional crop incomes (ACI) needs to be equated with discounted windbreak costs (Equation 3).

$$\sum_{t=0}^{n} \frac{ACI_t}{(1+i)^t} = PV_C \tag{3}$$

The left side of Equation 3 is rearranged and simplified in Equation 4 by employing a multiplier M (see Rose 1977).

$$ACI_0 \times \frac{1}{(1+i)^0} + ACI_1 \times \frac{1}{(1+i)^1} + \ldots + ACI_n \times \frac{1}{(1+i)^n} = ACI \times \frac{1}{M} \tag{4}$$

where:

$$M = \left[\frac{i \times (1+i)^n}{(1+i)^n - 1} \right] \quad \text{and} \quad ACI_0 = ACI_1 = ACI_n \tag{5}$$

Now, Equation 1 is restated as Equation 6 where *ACI* is equal to annual income from additional crop (maize) that is necessary to be generated every year during a windbreak lifespan in order to break even with windbreak establishment and management costs (PV_C).

$$ACI \times \frac{1}{M} = PV_C \tag{6}$$

Solving Equation 6 for *ACI* (additional crop income), we obtain Equation 7, which is equivalent to the formula for Annual Equivalent Value (for discussion on AEV see Klemperer 1996). Thus, *ACI* represents annual income from additional maize yield generated over the entire sheltered area.

$$ACI = PV_C \times M \tag{7}$$

And $ACI = \overline{P} \times ACY$ where $\overline{P}$ is fixed market price (producer takes the market price of maize). So, equation 7 is transformed to Equation 8.

$$\overline{P} \times ACY = PV_C \times M \tag{8}$$

Solving Equation 8 for *ACY* presents a total annual additional maize yield required to be accumulated over the entire sheltered area in order to break even with windbreak costs.

$$ACY = \frac{PV_C \times M}{\overline{P}} \tag{9}$$

where:

ACY = annual required additional maize yield (accumulated over the entire sheltered area)

To solve for additional maize yield per unit area Equation 9 is transformed into Equation 10.

$$ACY_{UA} = \frac{PV_C \times M}{\overline{P} \times A} \tag{10}$$

where:

ACY_{UA} = annual required additional maize yield accumulated over the unit of sheltered area (Mg^{-1} ha^{-1} yr^{-1})

$\overline{P}$ = fixed maize price of \$68.11 Mg^{-1} (\$1.73 bu^{-1}) (IDALS, 2001)

A = area of sheltered zone (ha)

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Figure 1. Illustration of yield increase in the leeward protected zone of a windbreak. Vertical scale of yield increase is exaggerated in order to present magnitudes of yield increase and yield loss. Adapted from GAO (1975) and Stoeckeler (1962). 1 - row of shrubs, 2 - row of silver maple, 3 - row of poplar, YL - yield loss on the leeward protection zone, ACY - additional crop yield on the leeward protection zone and UY - unprotected yield.

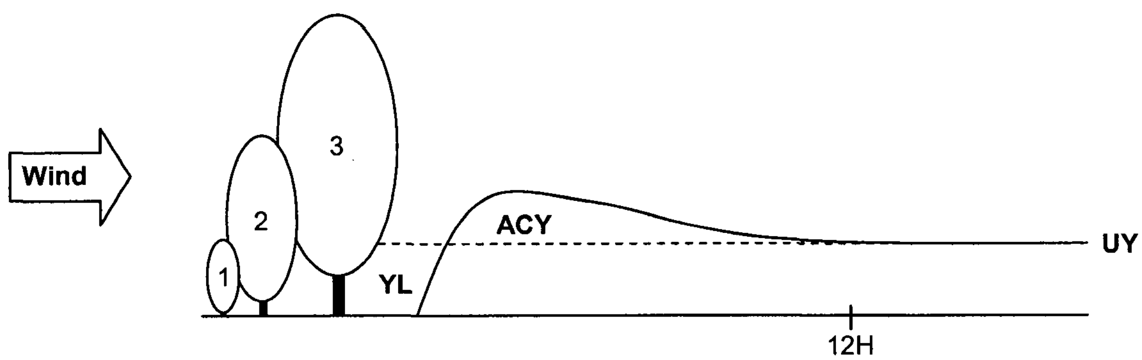

Figure 2. Layout of mixed windbreak design. Most likely sheltered scenario assumed (12H protection on the leeward side).

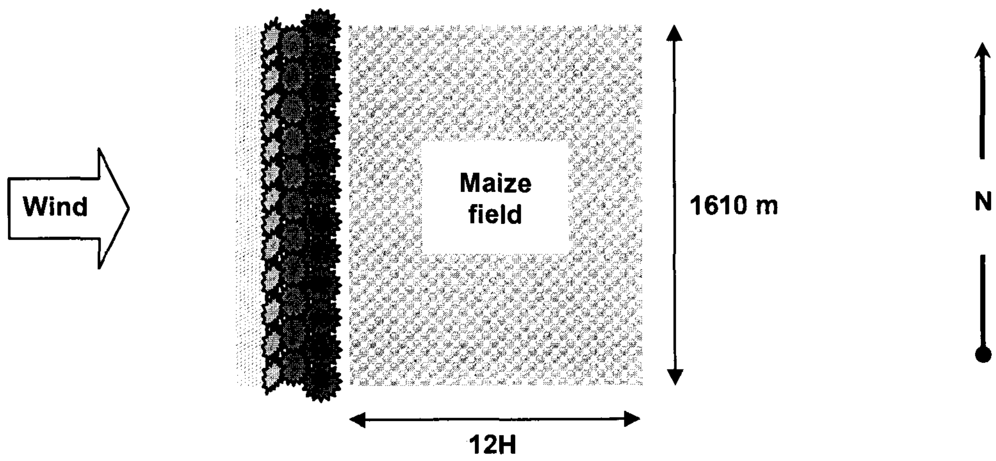

Figure 3. Predicted Present Value of windbreak cost (PVC) at 5% real discount rate for 1610-m windbreaks of different lifespans in Midwestern USA.

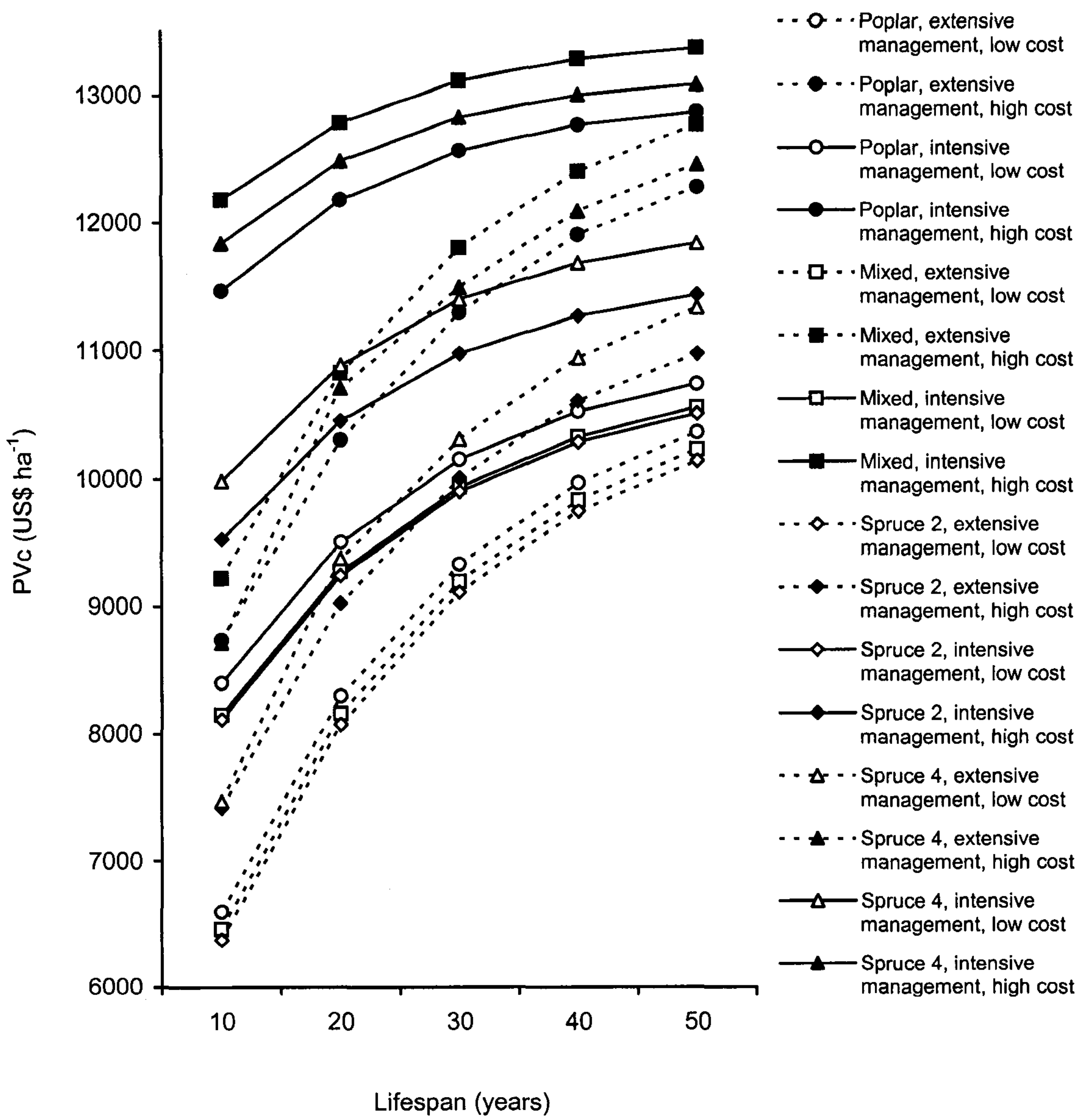

Table 1. Predicted transaction costs for a mixed windbreak planted in extensive scenario with lifespan of 50 years in Midwestern USA. Area: 1.18 ha, year 2000 costs.

Cost Item	**Year**	Unit Value (US$ ha^{-1})		Total Value (US$)	
		Low Cost	High Cost	Low Cost	High Cost
Plowing	0	22.24	34.60	26.24	40.82
Spraying	0, 1, 2, 3, 4, 5	135.54	172.61	159.94	203.68
Disking	0	19.77	32.12	23.33	37.91
Overhead/management	every year	32.12	32.12	37.91	37.91
Land rent	every year	345.95	345.95	408.23	408.23
Tree purchase cost	1	897.01	1973.42	1058.47	2328.64
Shrub purchase cost	1	493.36	601.00	582.16	709.18
Tree planting	1	412.62	861.13	486.90	1016.13
Shrub planting	1	206.31	430.56	243.45	508.07
Tree replanting	2, 3, 4	143.52	301.40	169.36	355.65
Shrub replanting	2, 3, 4	76.06	119.85	89.75	141.42
Pruning	every 3 years	2.42	4.82	2.86	5.69
Tree removal	50	434.91	830.29	513.20	979.74

Data source:

P. Wray, pers. comm. 2001.

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Table 2. Ranking of windbreak scenarios, depending on the quantity of additional maize yield needed to break even in Midwestern USA.

Rank	Windbreak Scenario	Break-even Additional Maize Yields (Mg ha^{-1})														
		Length of the Protected Zone														
		6H					12H					15H				
		Lifespan					Lifespan					Lifespan				
		10	20	30	40	50	10	20	30	40	50	10	20	30	40	50
1	Mixed, extensive[a)], low cost	4.39	1.35	0.84	0.65	0.56	2.20[c)]	0.68	0.42	0.33	0.28[d)]	1.76	0.54	0.34	0.26	0.22
2	Mixed, intensive[b)], low cost	5.53	1.54	[illegible]	0.68	0.57	2.77	0.77	0.46	0.34	0.29	2.21	0.62	0.36	0.27	0.23
3	Mixed, extensive, high cost	6.26	1.80	[illegible]	0.82	0.69	3.13	[illegible]	0.54	0.41	0.35	2.51	0.72	0.43	0.33	0.28
4	Mixed, intensive, high cost	8.27	2.12	[illegible]	0.88	0.73	4.14	[illegible]	0.60	0.44	0.36	3.31	0.85	0.48	0.35	0.29
5	Polar, extensive, low cost	7.47	2.29	1.43	[illegible]	[illegible]	3.73	[illegible]	0.71	0.55	0.47	2.99	[illegible]	0.57	0.44	0.38
6	Poplar, intensive, low cost	9.50	2.63	1.55	[illegible]	[illegible]	4.75	[illegible]	0.78	0.58	0.49	3.80	[illegible]	0.62	0.46	0.39
7	Spruce 2, extensive, low cost	6.22	2.33	1.55	[illegible]	[illegible]	3.11	[illegible]	0.78	0.60	0.50	2.49	[illegible]	0.62	0.48	0.40
8	Poplar, extensive, high cost	9.88	2.85	1.73	[illegible]	[illegible]	4.94	1.42	0.86	0.66	0.56	3.95	[illegible]	0.69	0.53	0.45
9	Poplar, intensive, high cost	12.98	3.37	1.92	1.41	[illegible]	6.49	1.68	[illegible]	0.70	0.58	5.19	[illegible]	0.77	0.56	0.47
10	Spruce 2, intensive, low cost	9.64	3.25	2.06	1.54	[illegible]	4.82	1.62	[illegible]	0.77	0.63	3.86	[illegible]	0.82	0.61	0.51
11	Spruce 2, extensive, high cost	8.82	3.17	2.08	1.58	[illegible]	4.41	1.59	[illegible]	0.79	0.66	3.53	[illegible]	0.83	0.63	0.53
12	Spruce 2, intensive, high cost	11.32	3.68	2.28	1.68	1.37	5.66	1.84	[illegible]	0.84	0.69	4.53	1.47	[illegible]	0.67	0.55
13	Spruce 4, extensive, low cost	9.71	3.60	2.34	1.79	1.49	4.85	1.80	[illegible]	0.89	0.74	3.88	1.44	[illegible]	0.72	0.60
14	Spruce 4, intensive, low cost	12.97	4.18	2.59	1.91	1.56	6.49	2.09	[illegible]	[illegible]	0.78	5.19	1.67	[illegible]	0.76	0.62
15	Spruce 4, extensive, high cost	11.32	4.12	2.61	1.98	1.64	5.66	2.06	[illegible]	[illegible]	0.82	4.53	1.65	[illegible]	0.79	0.66
16	Spruce 4, intensive, high cost	15.38	4.80	2.91	2.12	1.72	7.69	2.40	1.46	[illegible]	0.86	6.15	1.92	[illegible]	0.85	0.69

Break-even Additional Maize Yield ≤ 0.42 Mg ha^{-1} (Stoeckeler 1962)

Break-even Additional Maize Yield ≤ 0.89 Mg ha^{-1} (Kort 1988)

Break-even Additional Maize Yield ≤ 1.34 Mg ha^{-1} (Kort 1988)

[a)] extensive management: windbreak is removed at the end of lifespan
[b)] intensive management: windbreak is replanted at the end of lifespan to provide sheltering effect in the future
[c)] equivalent to 34.98 bu ac^{-1} yr^{-1} (1 bushel = 25.40 kg of maize, 1 acre = 0.4047 ha
[d)] equivalent to 4.43 bu ac^{-1} yr^{-}

CHAPTER 3: ECONOMIC EVALUATION OF POTENTIALS FOR CARBON STORAGE IN WOODY BIOMASS OF IN-FIELD WINDBREAKS[1]

A paper to be submitted to the Journal of Soil and Water Conservation

Robert K. Grala and Joe P. Colletti

Abstract

Four in-field windbreaks were evaluated in terms of economic efficiency of carbon sequestration. Two windbreaks – 4-row cottonwood and 2-row mixed species – are superior to spruce windbreaks (four and two rows) because expected carbon value equals establishment and annual management costs sooner. With above and below-ground carbon accounted and valued at a fixed price, a cottonwood windbreak breaks even within a 30-year lifespan. If only above-ground carbon is included, the cottonwood windbreak breaks even within a 40-year lifespan. Other windbreaks with lower carbon flux do not break even within maximum lifespan of 50 years. A cottonwood windbreak requires the lowest prices per unit of carbon to break even across the five life-spans examined.

Continuous Conservation Reserve Program (CCRP) payments cause rapid coverage of costs such that the cottonwood windbreak (valuing above or above and below-ground carbon) and mixed windbreak (above and below-ground carbon only) break even in 10 years. The spruce windbreaks require carbon flux beyond known capabilities.

[1] Paper presented at the 2002 Plains and Prairie Forestry Association Conference, July 30-August 1, 2002, Grand Junction, Colorado.

Key words: in-field windbreaks, carbon storage, break-even analysis, economic viability, Conservation Reserve Program.

Scientists have been observing unprecedented increases in the atmosphere concentration of greenhouse gases – GHGs (Berdowski et al., 2001; Claussen et al., 2001; Prather et al., 2001). Carbon dioxide (CO_2) it is the most abundant greenhouse gas and, therefore, has the greatest contribution to the global warming potential - GWP (Berdowski et al., 2001; Claussen et al., 2001; Kägi, 2000). For this reason, it is considered to be the main force affecting future climate change (Weyant, 1993). It is predicted that under different scenarios, future CO_2 concentration increase may lead to an increase in the earth's surface temperature of 1 to 6 degree Celsius by year 2100 (IPCC, 2001). Such a tremendous increase in the temperature is expected to significantly affect agriculture production, human living conditions, biodiversity, and economic development (Adejuwon, 2001; Claussen et al., 2001).

Because of these potential adverse effects the issue of an increasing concentration of CO_2 in the Earth's atmosphere is intensively discussed among researchers, politicians, and business representatives. Much discussion focuses on possible abatement instruments that cause a CO_2 decrease in the atmosphere. Proposals vary from implementing new abatement technologies to production systems utilizing alternative energy sources or employing efficiency measures for utilization of traditional fuels. To mitigate adverse effects of global warming, parties of the Kyoto Protocol[2] (1997) agreed to decrease their emissions of greenhouse gases by at least 5% below 1990 level in the commitment period 2008-2012 for the countries included in Annex I of the protocol.

Woody plants were recognized by Kyoto Protocol as an effective tool to offset part of CO_2 emissions. In comparison to other mitigation instruments, planting trees may provide a relatively inexpensive way to decrease the concentration of CO_2 as they can store carbon (C) for long time periods (Sampson and Sedjo, 1997). Most research on the cost effectiveness of using trees to decrease atmospheric concentration of CO_2 has focused on large scale forestry projects such as region, country, state, county or large-area forest plantations (Plantinga and Mauldin, 2001; Newell and Stavins, 2000; Cannell, 1999; Stavins, 1999; Ley and Sedjo, 1997; Parks et al., 1997). However, in states such as Iowa where agricultural production is the predominant this approach might be infeasible as large amounts of land would have to be removed from agricultural production. In-field windbreaks allow for storage of additional amounts of carbon while enabling agricultural production.

This paper focuses on windbreak projects that are assumed to fit in an operational farm and protect adjacent crops. The aim of the paper is to examine the economic viability of using four possible in-field windbreak designs as a means to absorb CO_2 from the earth atmosphere and store C in the woody biomass of trees (above and below ground). We take two approaches. First, we determine the required amounts of carbon that has to be accumulated in each of four windbreaks (considering five functional life-span lengths and given a carbon market price) to equal all windbreak costs. Second, as the market for carbon trading is not fully developed, we determine the required unit price for carbon that would

[2] Kyoto Protocol to the United Nations Framework Convention on Climate Change

have to be offered to the "carbon producers" with reported annual rates of carbon accumulation such that the carbon value equals (breaks even) the costs of establishing and managing the windbreaks[3]. These required prices are compared against published carbon prices by Chatterjee (2002), Perkins (1999) and Totten (1999)[4]. Finally, we examine the influence of government payments available through the USDA continuous Conservation Reserve Program (CCRP) on the required break-even amounts of carbon and prices for carbon storage.

Methods and Materials

In this paper, an economic analysis is employed to compare the costs of establishing and managing in-field windbreaks against the benefit (revenue) of storing carbon in the woody biomass (above and below ground) of such windbreaks. Because the market for carbon is developing, two approaches are adopted in this paper.

In the first approach we assume that the current market price for carbon storage equals a fixed payment offered to Iowa farmers (e.g. a Canadian utilities consortium has proposed a payment of $3.00 per acre for implementing soil carbon conservation practices)[5] (Perkins 1999). Then, given this price, the amounts of carbon (Q) that would have to be

[3] The preliminary results of this research were presented in a poster form during the Seventh Biennial Conference on Agroforestry in North America and the Sixth Annual Conference of the Plains and Prairie Forestry Association that was held on August 12-15, 2001 in Regina, Saskatchewan, Canada.

[4] Prices from year 1999 are inflated to year 2002 using the Consumer Price Index (CPI)

[5] The per hectare amount of carbon that should be accumulated in the soil in order to be eligible for carbon payments was not specified (Perkins, 1999); in this paper we assume no-till farming and corresponding yearly carbon accumulation.

accumulated in living windbreaks to break even are determined and compared with actual amounts of carbon accumulated in each windbreak.

In the second approach we calculate the required price (P) for storing one unit of carbon (Mg ha^{-1} yr^{-1}) for each windbreak at assumed rates of carbon accumulation. After break-even prices are calculated, they are compared with prices published in the literature (Chatterjee, 2002; Perkins, 1999; Totten, 1999).

In both approaches four in-field windbreaks are evaluated: 1) a cottonwood (*Populus deltoides*) windbreak planted with four rows, 2) a mixed (*Populus deltoides* and *Acer saccharinum*) windbreak planted with two rows, 3) a spruce (*Picea* spp.) windbreak planted with two rows and 4) a spruce windbreak planted with four rows. Each windbreak is examined at five life-span lengths: 10, 20, 30, 40 and 50 years. Carbon accumulated in woody biomass above and below ground is considered. It is assumed that carbon accounts for 50% of the dry woody biomass (Kort and Turnock, 1999).

Approach 1: Calculating break-even amounts of carbon at a given market price. It is assumed that the price for storing one unit of carbon is given by the market and the farmer-operator has no way to influence it. Further, it is presumed that a farmer's decision on whether to implement a windbreak investment or not depends solely on the possibility to break even at the specified price offered for carbon storage. A fixed price (market price) for storing one metric ton (Mg) of carbon is taken into consideration, and it is determined whether the expected accumulated mass of carbon would allow the owner to break even with the windbreak costs. The market price is based on an offer of $3.00/acre to Iowa farmers by a Canadian utilities consortium for implementing agricultural practices promoting storage of carbon in the soil (Perkins, 1999). Based on annual agronomic carbon accumulation of 0.4

Mg ha^{-1} yr^{-1} in crop fields (Cruse 2002, pers.comm.; Sandor 2002, pers.comm.; Marquez, 2001; USDA, 1975), this price converts to \$18.53 Mg^{-1} ha^{-1} yr^{-1} (\$20.00 Mg^{-1} ha^{-1} yr^{-1} when adjusted to year 2002) in Iowa soils. The required amounts of carbon accumulation are then compared against estimated amounts of carbon accumulation in windbreaks (Kort and Turnock, 1998). This approach includes several steps presented below.

The model for Approach 1 allows for calculating required amounts of carbon that need to be accumulated in woody biomass of windbreaks in order to break even, given market price offered for storing one unit of carbon (Mg ha^{-1} yr^{-1})[6].

The foundation of this model is that windbreak establishment and maintenance costs incurred over time can be easily determined. Further, we assume that market price for carbon is known. An owner breaks even with a windbreak investment at a point when payments received for carbon storage equal the costs incurred to establish and maintain the windbreak. This break-even relationship is represented by Equation 1.

$$\sum_{t=1}^{n} CP = \sum_{t=0}^{n} C \tag{1}$$

where:
CP = carbon payments paid to the owner for carbon storage at the end of each year, starting t = 1
C = costs incurred during windbreak life-span
t = year, at which payment or cost occurred; t = 0, 1, 2, 3…n
n = length of a windbreak life-span (10, 20, 30, 40 or 50 years)

Carbon payments and costs are incurred over time, so they need to be discounted to be comparable. Consequently, Equation 1 is modified into Equation 2.

[6] We also applied this method to calculate break-even corn yields within protected zone of a windbreak (Grala and Colletti, 2003).

$$PV\ TCP = PV\ TC \tag{2}$$

where:
PV TCP = Present Value of Total Carbon Payments accumulated over windbreak life-span
PV C = Present Value of the costs incurred during windbreak life-span

Income for carbon storage is assumed to occur at the end of every year during the life-span based on anticipated future carbon sequestration[7]. The Present Value of total carbon income includes payments that are obtained each year during the windbreak life-span and are discounted to year 0 (Equation 3).

$$PV\ TCP = \sum_{t=1}^{n} CP_t \times (1+i)^{-t} = \frac{CP_1}{(1+i)^1} + \frac{CP_2}{(1+i)^2} + \frac{CP_3}{(1+i)^3} + \ldots + \frac{CP_n}{(1+i)^n} \tag{3}$$

where:
PV TCP = Present Value of total carbon payments accumulated over the windbreak life-span
CP_t = carbon payment received at the end of the year
t = year, at which payment was obtained; t = 1, 2, 3 … n
i = real interest rate
n = length of a windbreak life-span (10, 20, 30, 40 or 50 years)

Windbreak costs of various types are incurred every year over the windbreak life-span. Costs are assumed to occur at the end of the year and are discounted accordingly (Equation 4). Windbreak establishment starts with site preparation that occurs at year 0.

$$PV\ C = \sum_{t=0}^{n} C_t \times (1+i)^{-t} = \frac{C_0}{(1+i)^0} + \frac{C_1}{(1+i)^1} + \frac{C_2}{(1+i)^2} + \ldots + \frac{C_n}{(1+i)^n} \tag{4}$$

---

[7] The anticipated rate of carbon sequestration is based on mean annual increment (MAI) of woody biomass accumulated above ground. MAI is an average growth of the forest stand until the age considered (in this case it is the length of a windbreak life-span) and is obtained by dividing the corresponding volume by this age.

where:
PV C = Present Value of the costs incurred during the windbreak life-span
C_0 = establishment cost, t = 0
C_t = cost incurred in particular year
t = year, at which cost was incurred; t = 0, 1, 2 … n
i = real interest rate
n = length of a windbreak life-span (10, 20, 30, 40 or 50 years)

Set (3) equal to (4) as shown in Equation 5. To break even, the Present Value of discounted carbon payments (PV TCP) accumulated over the windbreak life-span has to be at least equal the Present Value of the windbreak costs (PV C).

$$\frac{CP_1}{(1+i)^1}+\frac{CP_2}{(1+i)^2}+\frac{CP_3}{(1+i)^3}+\ldots+\frac{CP_n}{(1+i)^n}=\frac{C_0}{(1+i)^0}+\frac{C_1}{(1+i)^1}+\frac{C_2}{(1+i)^2}+\ldots+\frac{C_n}{(1+i)^n} \tag{5}$$

To simplify:

$$\frac{CP_1}{(1+i)^1}+\frac{CP_2}{(1+i)^2}+\frac{CP_3}{(1+i)^3}+\ldots+\frac{CP_n}{(1+i)^n}=PV\ C \tag{6}$$

Because incomes for carbon storage are assumed to occur on a yearly basis in equal amounts, Equation 6 is rearranged as Equation 7.

$$CP_1\times\frac{1}{(1+i)^1}+CP_2\times\frac{1}{(1+i)^2}+CP_3\times\frac{1}{(1+i)^3}+\ldots+CP_n\times\frac{1}{(1+i)^n}=PV\ C \tag{7}$$

The Left-Hand-Side (LHS) of Equation 7 represents carbon payments that are paid in equal amounts every year. To simplify, a multiplier "M" is employed (Equation 8) (see Rose 1977).

$$CP \times \frac{1}{M} = PV\ C \tag{8}$$

where:

$$M = \left[\frac{i \times (1+i)^n}{(1+i)^n - 1} \right]$$

Now, Equation 8 is solved for CP, the annual carbon income payment (Equation 9).

$$CP = PV\ C \times M \tag{9}$$

Further, CP in Equation 9 is a product of unit price for carbon ($\overline{P}$) and the yearly amount of carbon accumulated in the woody biomass, Q (in Equation 10).

$$\overline{P} \times Q = PV\ C \times M \tag{10}$$

So, for the first approach the price for carbon ($\overline{P}$) is given and owner can choose a windbreak design and influence the amount of carbon accumulated in its woody biomass (Q). Therefore, Equation 10 is solved for the required annual quantity of carbon that has to be accumulated in woody biomass of the windbreak in order to break-even (Equation 11).

$$Q = \frac{PV\ C \times M}{\overline{P}} \tag{11}$$

Finally, because $PV\ C \times M = AEV$ (Annual Equivalent Value), then Equation 11 is rewritten as Equation 12.

$$Q = \frac{AEV}{\overline{P}} \tag{12}$$

Approach 2: Calculating a required break-even carbon price. We recognize that the market for carbon storage is still developing. Therefore, the price of storing one metric ton of carbon in woody biomass of windbreak is calculated. This computed price would have to be paid to the windbreak owner for each unit of carbon stored such that costs are covered. Carbon data by Kort and Turnock (1998) are used. Computed prices for carbon storage are compared against carbon prices reported in the literature.

Equation 12 is solved for the required price that would need to be offered to the owner to break even at given windbreak costs and expected carbon accumulation rates (Equation 13).

$$P = \frac{AEV}{\overline{Q}} \tag{13}$$

Results and Discussion

Present Value cost for each windbreak. To establish the break-even amounts of carbon, it is necessary to estimate the costs that were incurred to establish and manage selected windbreaks and properly discount them. A real discount rate, i = 0.05, was used. Costs for a mixed (2-row) windbreak are presented in Table 1. Present Values costs for each windbreak and life-span length are presented in Table 2.

Table 2 reveals that the least costly windbreak is a 2-row spruce windbreak across all life-span lengths considered. In contrast, the most costly scenario is cottonwood windbreak also across all life-span lengths. As life-span increases, so does the cost, but at a decreasing rate.

Required Break-even Amounts of Carbon – Q. The break-even amount of carbon (Q) is the amount that has to be accumulated in a windbreak to generate enough revenues to offset the costs incurred to establish and manage the windbreak (including land rent). Equation 12 is used to calculate annual break-even amounts of carbon.

Published carbon accumulation (above ground) by Kort and Turnock (1998) were used to compare against the required break-even amounts of carbon. It is assumed in this model that additional 30% of above-ground carbon amount is accumulated below ground – in roots (Kort and Turnock, 1999). The estimates for above-ground, above and below-ground, and break-even amounts of carbon for four in-field windbreaks are presented in Figures 1, 2, 3, and 4.

For the cottonwood windbreak (Figure 1) it is possible to accumulate enough carbon within a 40-year life-span considering only the above-ground carbon accumulation. It is impossible to accumulate enough carbon to break even for this windbreak for 10, 20, 30-year life-spans. Thus, it is clear that 40 years is the shortest life-span for a 4-row cottonwood windbreak to accumulate enough carbon to offset windbreak costs. With carbon above and below-ground accounted for, the required carbon is accumulated within a 30-year life-span.

Inspection of Figures 2, 3 and 4 reveals that none of the other windbreaks examined (mixed planted in two rows and spruce planted two and four rows) are likely to accrue enough carbon for any of the five life-spans. Actual accumulation of above and below ground carbon rises steadily as the life-span of a windbreak is lengthened; however, the mixed and spruce windbreaks still do not accrue enough carbon. The smallest amount of carbon is accumulated in a 2-row spruce windbreak, followed by 4-row spruce windbreak and by 2-row mixed windbreak. For instance, if a 50-year life-span, which accumulates the largest amount of carbon, is examined, then carbon buildup both above and below ground equals to 4.01 Mg ha^{-1} yr^{-1}, 6.03 Mg ha^{-1} yr^{-1} and 24.52 Mg ha^{-1} yr^{-1} for a 2-row spruce, 4-rows spruce and 2-row mixed windbreak, respectively. Examination of a 50-year life-span shows carbon deficiencies (the difference between break-even amount and actual above and below-ground carbon accumulation)) of 20.81 Mg ha^{-1} yr^{-1}, 19.29 Mg ha^{-1} yr^{-1} and 1.77 Mg ha^{-1} yr^{-1}, respectively.

Computed price for carbon stored. Examination of Figure 5 reveals that, as expected, spruce windbreak planted in two rows requires the highest break-even carbon prices across all life-spans considered, followed by spruce planted in four rows, mixed windbreak planted in two rows and cottonwood planted in four rows. The break-even carbon price is directly related to the amount of carbon accumulated in the woody biomass of a windbreak. Because there is less carbon accumulated in spruce windbreaks, they require much higher annual prices for carbon to offset the costs. For example, for spruce planted in two rows, the break-even carbon price is about \$335.56 Mg^{-1} ha^{-1} yr^{-1} if a 10-year life-span is implemented and about \$123.72 Mg^{-1} ha^{-1} yr^{-1} if a 50-year life-span is used (accounting above and below ground carbon accumulation). These values are nearly 17 and 6 times higher, respectively, than a comparison price of \$ 20.00 Mg^{-1} ha^{-1} yr^{-1} (based on Canadian utilities consortium's market price).The cottonwood windbreak planted in four rows is superior in terms of required carbon price. The expected per area carbon accumulation is much higher than in other windbreaks because cottonwood maintains a faster growth rate and there are more trees planted per area in this windbreak. If a 10-year life-span is considered (above and below ground carbon accumulation), the required break-even carbon price for a cottonwood windbreak is only about 3 times higher than the market price of \$20.00 Mg^{-1}. If the life-span is extended to 30 years, the required break-even price is lower than the market price (by \$4.08); for 40 and 50-year life-spans, the required break-even price is lower by \$8.34 and \$10.77. If only above ground carbon accumulation is considered, more time is needed to accumulate the amount of carbon that would approach the comparison market price (40 years).

In a case of mixed and 2-row and 4-row spruce windbreaks the required break-even prices are significantly higher than the market price of \$20.00 Mg^{-1}. However, if the carbon market price was 32.38 Mg^{-1}, it would be also possible to break-even by planting a 2-row mixed windbreak with 50-year life-span (above ground carbon accumulation) and 40-year life-span (above and below ground carbon accumulation).

USDA Conservation Reserve Program (CRP) payments. Most costs incurred during the life-span of a windbreak occur in the early stages of the project. For this reason, in a case of short life-spans, like 10, 20 or 30 years, the rate of carbon accumulation within a windbreak would have to be relatively high to generate revenue large enough to cover these costs. Our results show that the actual amounts of carbon accumulated in considered windbreaks with short life-spans are significantly lower than those required to break-even financially.

Payments available through the 2002 continuous Conservation Reserve Program (CRP) of the USDA provide significant coverage of the windbreak costs and should allow a farmer to achieve required amounts of carbon even with shorter life-spans. We examine the influence of CRP payments on the viability of carbon sequestration in windbreaks. There are two contract durations, 10 and 15 years, available through the program for qualified in-field windbreaks and shelterbelts (USDA 1997). We assume a 10-year contract for a 10-year windbreak life-span and a 15-year contract for 20, 30, 40 and 50-year life-spans. Further, we assume that CRP payments include 120% rent payment for the duration of the contract, a bonus of \$10 ac^{-1} yr^{-1} (\$24.71 ha^{-1} yr^{-1}) of the contract duration paid up-front to the farmer, 50% cost-share of establishing a windbreak (USDA 1997) and an additional 40% enhancement incentive. Results are presented in Figures 6, 7, 8 and 9.

Because of the positive financial impact of the CRP, it is clear that for a 4-row cottonwood windbreak an owner is able to achieve more carbon than is required to break-even across five life-spans considering both, above and, below and above ground carbon. In terms of a 10-year life-span, the "excess of carbon" is 7.35 Mg ha^{-1} yr^{-1}, whereas for 50-year life-span it is 50.95 Mg ha^{-1} yr^{-1} (Figure 6). Clearly, longer life-span windbreaks accumulate more carbon than is necessary to offset the windbreak costs. Thus, an owner is able to make a profit from the carbon. A similar relationship is observed in the case of a 2-row mixed windbreak with an exception of a 10-year life-span, in which the actual carbon accumulation (above ground) is slightly smaller than a minimum amount required to break-even (by 0.80 Mg ha^{-1} yr^{-1}) (Figure 7).

In a case of spruce windbreaks (2 and 4-row) with CRP payments there is still not enough carbon accumulated to break-even with the investment at any of the five life-spans considered. However, the deficiencies of carbon are considerably lower than without CRP payments. For example, for the 2-row spruce (above and below ground carbon accumulation) windbreak, the deficiency is 1.18 Mg ha^{-1} yr^{-1} for a 10-year life-span and 4.44 Mg ha^{-1} yr^{-1} for a 50-year life-span (Figure 8). In the case of 4-row spruce, it is 0.86 Mg ha^{-1} yr^{-1} and 2.71 Mg ha^{-1} yr^{-1}, respectively (Figure 9). Interestingly, in the case of 4-row spruce windbreak, the carbon deficiency decreases initially and increases with a life-spans longer than 20 years as the CRP payments are provided only up 15 years. Therefore, after the contract expires, the cost accumulation is higher than the offsetting value of carbon. Thus, relatively more carbon would have to be accumulated to offset the windbreak cost. For the 2-row spruce windbreak, carbon deficiency increases for any rotation longer than 10 years.

Considering approach 2, Figure 10 shows that prices required to break-even are significantly lower with the CRP payments. For the four windbreaks considered, the cottonwood windbreak requires the lowest prices per unit of carbon to break-even. However, if a 10-year life-span is applied, only a cottonwood windbreak (with above and below ground carbon accumulation) attains the break-even price lower than the comparison price of \$10.48 Mg^{-1} (Chatterjee, 2002). In contrast, if a 50-year life-span is considered, both cottonwood and mixed windbreaks accumulate enough carbon to maintain the break-even price lower than \$10.48 Mg^{-1}. If the market price for carbon reaches the level of \$32.38 Mg^{-1}, then it would be possible to offset the windbreak costs with any of the five life-spans for cottonwood or mixed windbreak. A 2-row spruce windbreak requires break-even prices that are higher than those predicted in the future carbon market for any of the five life-spans considered if only above ground carbon is considered. However, if both above and below ground carbon are accounted for, then required break-even price is lower than \$32.38 Mg^{-1} for the 10 and 20-year life-spans. In a case of 4-row spruce windbreak (above ground carbon) the break-even price is lower for a 20-year life-span and higher for the 10, 30, 40 and 50-year life-spans. For a 4-row spruce windbreak with (above and below ground carbon) the required break-even prices are lower than the comparison market prices across all five life-spans considered. In contrast to a 4-row cottonwood windbreak, the required break-even prices for spruce windbreaks increase if life-span is extended from 20 to 40 years and decrease again if life-span is lengthened from 40 to 50 years. This peculiar pattern is due to non-uniform cash flows from CRP payments that are terminated after 15 years, low rate of carbon buildup and relatively high cost incurred after the termination of the CRP payments.

Summary and Conclusions

The break-even analysis conducted in this paper has shown that the viability of four windbreaks depends heavily on the amount of carbon accumulated and the costs incurred to establish and maintain the windbreak. Accordingly, carbon buildup within a windbreak depends on rate of tree growth, number of trees planted per area and length of the windbreak life-span. Trees that grow faster accumulate greater amount of woody biomass over the examined life-span and, therefore, there is more carbon.

While some costs increase proportionally to the number of trees planted (like seedling, tree planting, and replanting costs), other costs are fixed (e.g. land rent and management). Thus, for denser windbreaks (more trees per unit area), such as the 4-row cottonwood with more trees, the carbon accumulation is greater than the increase in costs and it is possible to break-even within a shorter life-span for a given market price of carbon. This also means that for the same period of time, the required carbon price is lower.

Clearly, if a windbreak life-span is longer, more woody biomass and carbon is accumulated. Thus, extending the life-span may provide an opportunity to accumulate carbon at relatively lower cost and allow for break-even points to be achieved.

Our analysis reveals that if continuous CRP payments are not provided only a 4-row cottonwood windbreak permits an owner to break-even within the life-span lengths considered at a given market price of \$20.00 Mg^{-1} ha^{-1} yr^{-1}. If only above ground carbon accumulation is considered, the break-even point occurs within a 40-year life-span, whereas if both above and below ground carbon accumulation is taken into consideration, it is possible to break-even within a 30-year life-span. And, from a required price perspective, CRP enables the lowest break-even carbon prices for each life-span length considered.

If a low break-even price of carbon (\$10.48 Mg^{-1}) is considered, then only a cottonwood windbreak with a 50-year life-span can produce enough revenue to break-even if above and below ground carbon is accounted for. In contrast, if required carbon prices are evaluated against a comparison price of \$32.38 Mg^{-1}, then for a 4-row cottonwood windbreak a break-even point can be achieved in 20 and 30 years, whereas a 2-row mixed windbreak can break-even with 40-year life-span valuing above and below ground carbon and with a 50-year life-span valuing above ground carbon only.

CRP payments lower significantly the required amounts of carbon as well as required carbon prices. With a cottonwood windbreak, it is possible to accumulate enough carbon value to break-even within 20-year life-span if compared against the lowest examined price of \$10.48 Mg^{-1} and in 10 years, if compared against a carbon price of \$20.00 Mg^{-1} (for above ground carbon accumulation only). In contrast, if above and below ground carbon is considered, it is possible to break-even with 10-year life-span comparing against price of \$10.48 Mg^{-1}. For the mixed windbreak with above and below carbon accumulation it is possible to achieve a break-even price lower than \$10.48 Mg^{-1} within 20-year life-span and in 50 years if only above ground carbon is accounted for. A market price of \$32.38 Mg^{-1} would allow to break-even within a 10-year life-span for cottonwood and mixed windbreak (both above and above and below ground carbon) as well as for spruce windbreaks (accounting for above and below ground carbon). However, for the 2-row spruce with a life-span longer than 20 years the required break-even carbon prices become larger than \$32.38 Mg^{-1}. In the case of the 2-row spruce and above ground carbon accumulation only, the required carbon prices are higher across five life-spans.

Our results show that the economics of windbreaks can be improved if carbon payments are available. However, this economic analysis was conducted only with respect to carbon storage and, therefore, economic viability of windbreaks is underestimated. The primary benefit is crop yield enhancement, which is provided by windbreaks simultaneously with carbon accumulation. Therefore, future economic analysis of windbreaks will consider joint benefits (crop yield enhancement in windbreak's adjacent field and carbon sequestration). This will facilitate optimization of windbreak net benefits to landowners and society.

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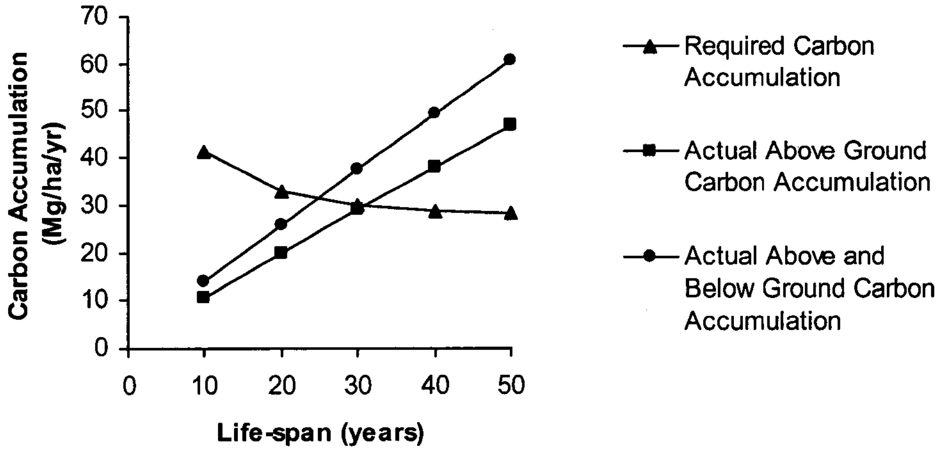

Figure 1. Break-even analysis for carbon accumulation in cottonwood windbreak (4 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

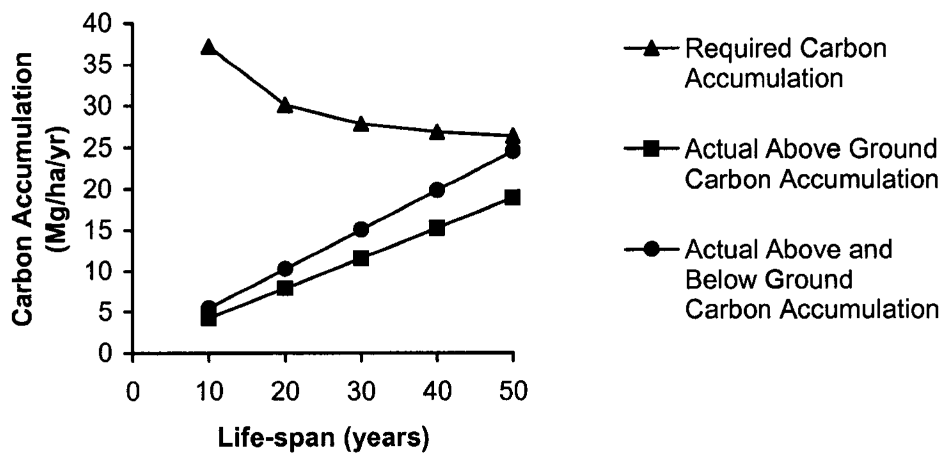

Figure 2. Break-even analysis for carbon accumulation in mixed windbreak (2 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

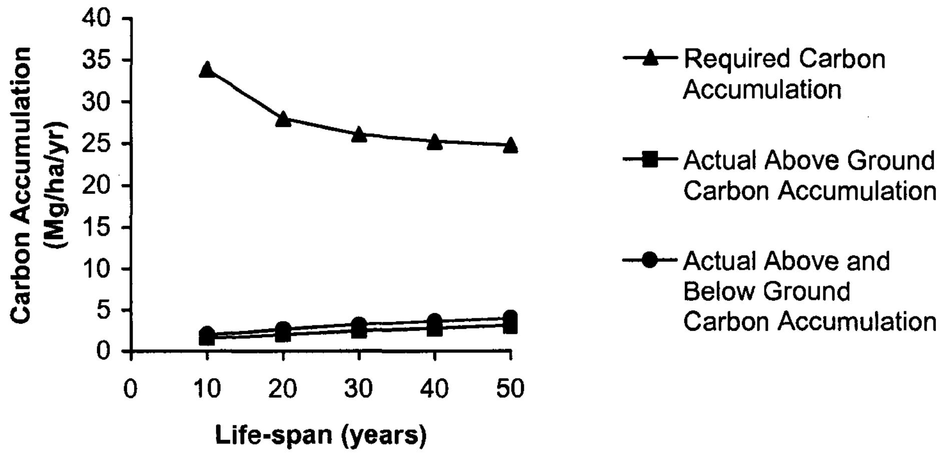

Figure 3. Break-even analysis for carbon accumulation in spruce windbreak (2 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

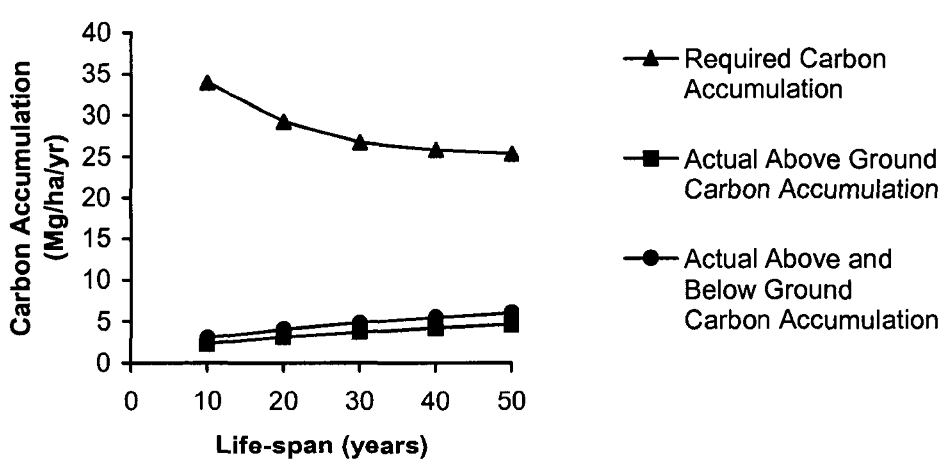

Figure 4. Break-even analysis for carbon accumulation in spruce windbreak (4 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

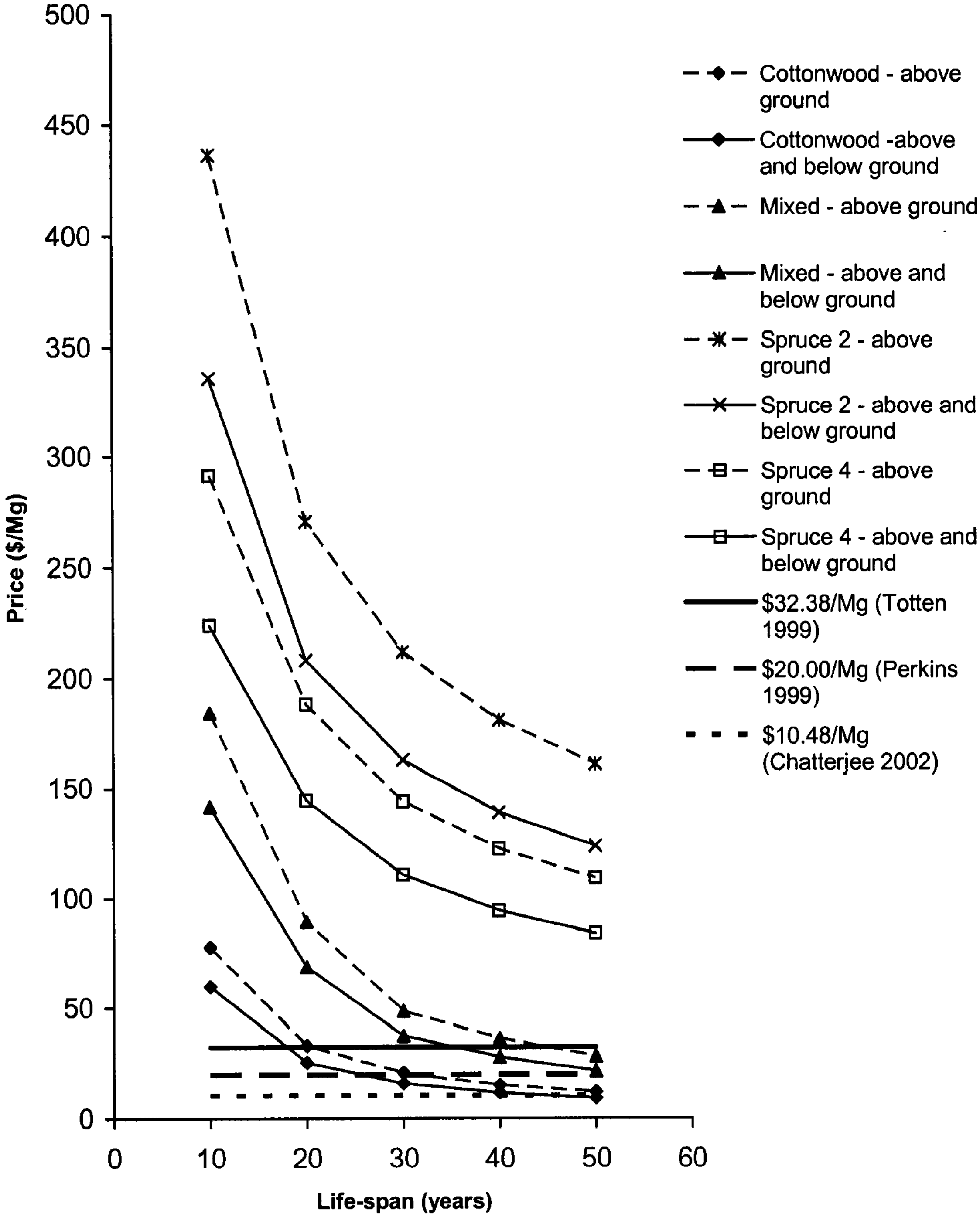

Figure 5. Computed break-even price for carbon accumulated by windbreak types and by life-span lengths compared against prices by Totten (1999), Perkins (1999) and Chatterjee (2002).

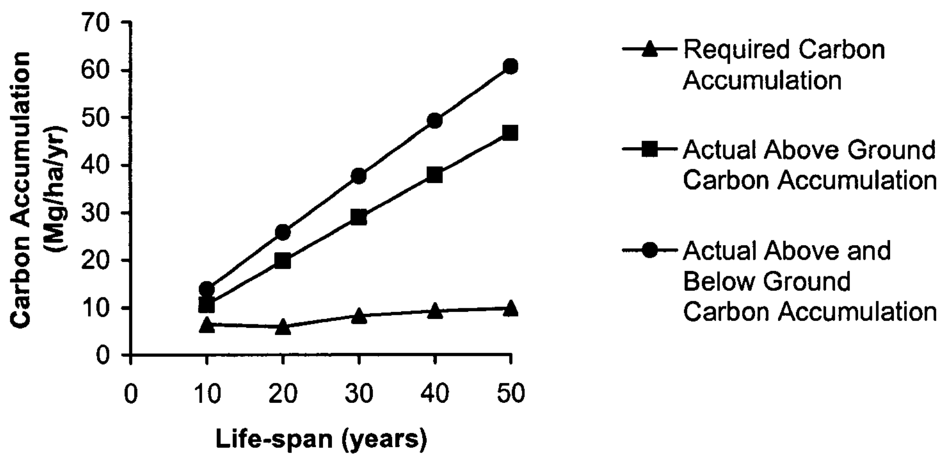

Figure 6. Break-even analysis for carbon accumulation in cottonwood windbreak (4 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

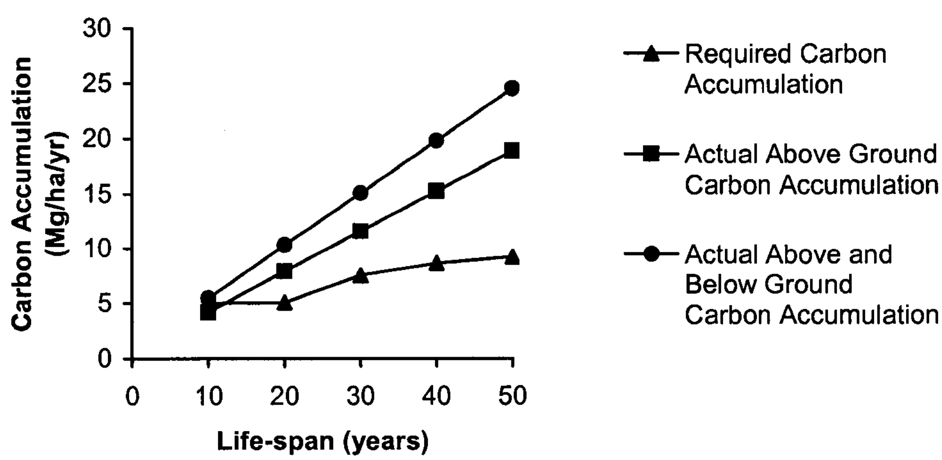

Figure 7. Break-even analysis for carbon accumulation in mixed windbreak (2 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

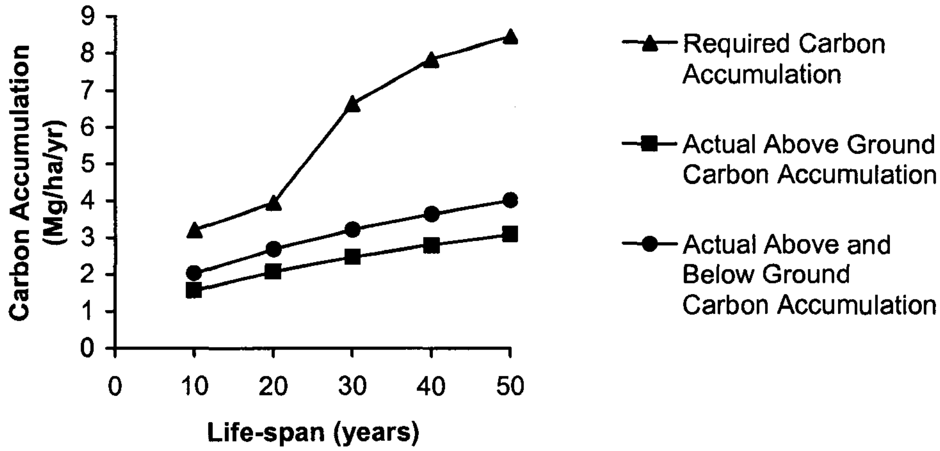

Figure 8. Break-even analysis for carbon accumulation in spruce windbreak (2 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

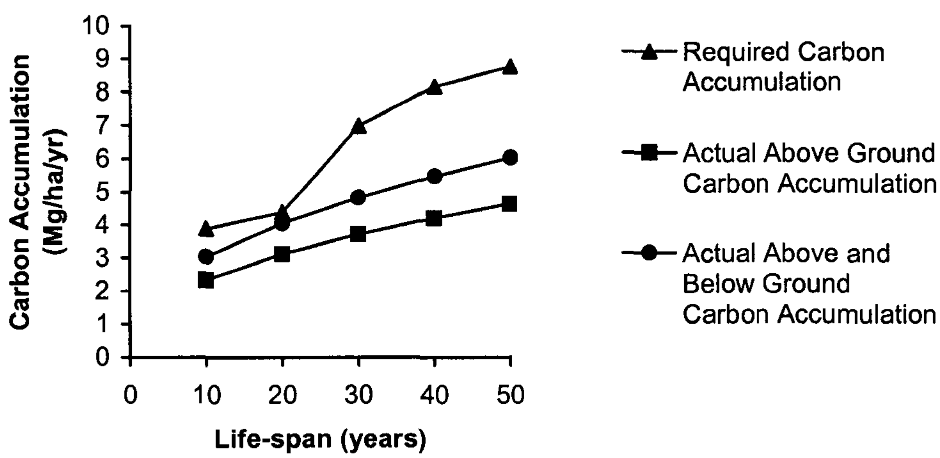

Figure 9. Break-even analysis for carbon accumulation in spruce windbreak (4 rows). Actual rates of carbon accumulation above ground are taken from Kort and Turnock (1998).

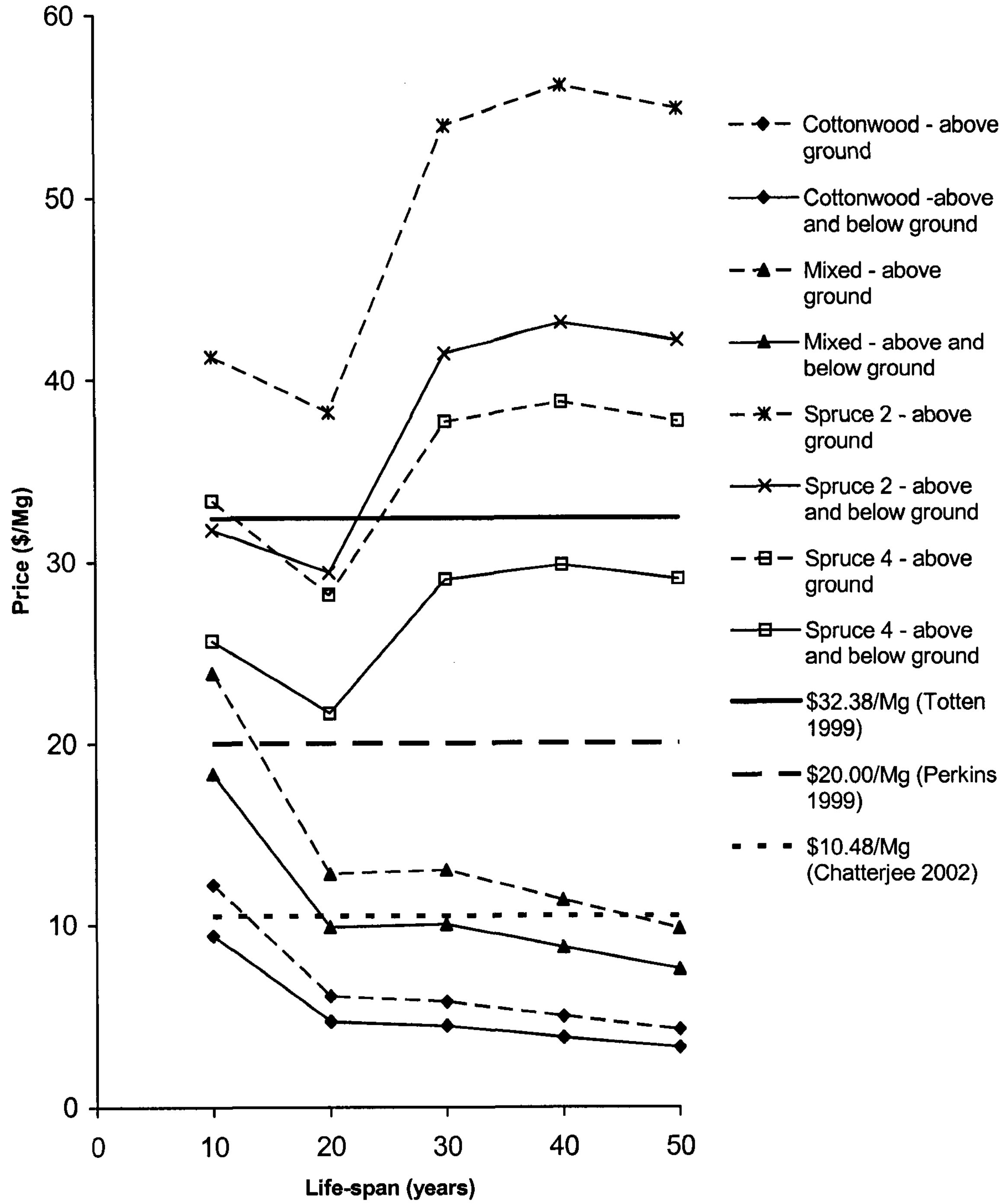

Figure 10. Required break-even price for carbon accumulated by windbreak types and by life-span lengths with continuous CRP payments. Comparison with carbon prices by Totten (1999), Perkins (1999) and Chatterjee (2002).

Table 1. Example cash flows for mixed windbreak (2 rows) planted with 50-year life-span. Costs as of year 2002. Average cost scenario was assumed.

Cost	**Year**	**Value** ($ ha^{-1})
Plowing	0	27.92
Spraying	0	79.69
Disking	0	27.18
Overhead/management	every year	34.60
Land rent	every year	358.31
Tree purchase cost	1	1022.60
Tree planting	1	287.04
Spraying	1	79.69
Tree replanting	2-4	111.94
Spraying	2-5	79.69
Pruning	every 3 years	31.38
Tree removal	50	600.48

Source: Edwards et al. 2002, Duffy and Smith 2002, Wray 2002 (pers.comm.), Cascade Forestry Service, Inc. 2001, Kort et al. 1994.

Table 2. Present Value Cost ($ ha^{-1} yr^{-1}) across windbreak designs by life-span length calculated at 5% real discount rate using year 2002 costs for custom operations.

Windbreak Type	**Rotation Length** (years)				
	10	**20**	**30**	**40**	**50**
Cottonwood Windbreak (4 rows)	640[a]	410	310	250	200
Mixed Windbreak (2 rows)	570	380	290	230	190
Spruce Windbreak (2 rows)	520	350	270	220	180
Spruce Windbreak (4 rows)	520	370	270	220	180

[a]Rounded to nearest ten dollars

CHAPTER 4: ECONOMIC FEASIBILITY FOR ENHANCING HUNTING OPPORTUNITIES THROUGH PLANTING IN-FIELD SHELTERBELTS: FARMERS' VIEW

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Abstract

Four focus groups were organized in Northeastern Iowa in 2004 to assess opportunities for hunting in in-field shelterbelts and on adjacent lands. A majority of respondents (95%) allowed/practiced some hunting on their lands. About 55% of respondents indicated that a potential exists for developing a fee hunting market associated with in-field shelterbelts. Intangible features of hunting, such as recreation/enjoyment and better stewardship of the land were ranked higher than tangible ones – additional income and provision of economic opportunities for the local community. Respondents were highly concerned with negative consequences of hunting – trespassing and hunters' misconduct. On average, agricultural producers were willing to accept (WTA) \$22.74 per visit per party of four hunters to allow hunting of pheasants on their land. About 33% would allow hunters free of charge. Those who owned an in-field shelterbelt required monetary compensation twice as much (\$35.86) as those who did not own one (\$15.00).

Keywords: fee hunting, focus groups, in-field shelterbelts, pheasant hunting, willingness to accept.

Providing wildlife habitat for hunting associated with in-field shelterbelts can provide agricultural producers with valuable conservation benefits and diversification of their farm income at the same time (Smith et al., 1992). There is considerable evidence in the literature that in-field shelterbelts can provide landowners with many tangible benefits, such as reduced soil erosion, livestock protection, increased crop yield, carbon sequestration, snow retention, and wildlife habitat (Brandle et al., 2004; Kort and Turnock, 1999; Johnson et al., 1991; Brandle et al., 1992; Baer, 1989; Kort, 1988). However, the number of acres enrolled in the Continuous Conservation Reserve Program (CCRP) clearly shows that in-field shelterbelts (also known as field windbreaks) are one of the least commonly adopted conservation practices, despite extensive cost-share assistance (FSA, 2004; Marsh, 1999). For example, in Iowa out of nearly 1.8 million acres enrolled in the Conservation Reserve Program for years 1986-2005, only about 5,800 acres were used to plant in-field shelterbelts – about 0.3% (FSA, 2004).

Many agricultural producers seemingly avoid planting in-field shelterbelts because land is taken out of crop production, unacceptable competition with adjacent crops for light, water and nutrients occurs, and interference with farm operations increases costs (Laughlin, 1989; Kort, 1988; Dearmont et al., 1983). In addition, in-field shelterbelts require commitment of significant financial resources at startup, whereas benefits are delayed in time (Baer, 1989) and often depend on factors beyond a producer's control (Marsh, 1999).

Economic analyses of shelterbelt effectiveness have focused mostly on crop yield increases on agricultural fields adjacent to in-field shelterbelts (Grala and Colletti, 2003; Brandle et al., 1992; Brandle et al., 1984; Frank et al., 1977; McMartin et al., 1974; Stoeckeler, 1963). Still, there is a compelling need to investigate other shelterbelt benefits that could provide agricultural producers with additional income and reduce uncertainty associated with shelterbelt performance, enough so to increase the acres planted.

In the Midwest USA, where the landscape is dominated by agricultural fields and the weather is conducive, in-field shelterbelts can enhance hunting opportunities. Shelterbelts have proven to attract many species of birds and animals by providing shelter and nesting and foraging places (Brandle et al., 2004; Strine, 1999; Burel, 1996; Burel and Baudry, 1995; Johnson et al., 1991; Johnson and Beck, 1988). In-field shelterbelts and adjacent areas are frequently utilized by hunters in Kansas because of greater probability of a successful hunt (Cable and Cook, 1990). Consequently, in-field shelterbelts could help generate significant income for farmer and the state economy (Cable and Cook, 1990; Johnson and Beck, 1988).

Whereas a beneficial role of in-field shelterbelts in enhancing wildlife habitat has been widely documented in the literature, the economic aspects of hunting in them and on lands adjacent to in-field shelterbelts have been examined only to a limited extent and mostly from a hunter perspective (Cook and Cable, 1990; Cable and Cook, 1990). The hunter viewpoint is important to assess the demand for hunting. However, it is equally essential to investigate farmer opinions, ideas, and attitudes about in-field shelterbelts to reveal their willingness to supply wildlife habitat associated with in-field shelterbelts.

In this paper, an evaluation of farmer attitudes toward hunting and their willingness to provide hunters with access to the shelterbelt wildlife at various threshold prices is presented.

Also, relationships between various shelterbelt attributes, such as shelterbelt ownership, shelterbelt condition, expected shelterbelt benefits and costs, and reasons for shelterbelts establishment, are explored to provide predictive ability for non-market values from hunting in and near in-field shelterbelts.

Methods and Materials

Opinions about in-field shelterbelts and hunting on lands adjacent to them were revealed through a set of focus groups (Litoselliti, 2003; Morgan, 1997; Stewart and Shamdasani, 1990). The study involved conducting four focus group sessions in four counties of Northeastern Iowa: Chickasaw, Butler, Floyd and Cerro Gordo. A total of 47 respondents participated in the study; 15, 10, 12 and 10, respectively, in each county (45 usable questionnaires were obtained). Respondents consisted of agricultural producers identified with assistance of county US Department of Agriculture Natural Resource Conservation Service (NRCS) staff.

Focus group format. The focus group session included of a 45-minute moderated discussion followed by a 20-minute questionnaire. The purpose of the discussion was to provide respondents with an opportunity to express their general opinions of in-field shelterbelts and hunting that might be otherwise difficult to capture in the questionnaire format. The questionnaire was designed to provide responses to specific questions related to in-field shelterbelts that would later facilitate a quantitative analysis.

Questionnaire format. A questionnaire was administered at the end of each focus group session; it consisted of 33 questions and was divided into four sections. In the first section, respondents were asked questions related to the in-field shelterbelts on their land or those that they were most knowledgeable about and their experiences with hunting. The second section contained questions related to assistance programs and benefits, cost, and negative effects of in-field shelterbelts. In the third section, a hypothetical in-field shelterbelt system was described, and respondents were asked to state the level of monetary compensation that they would need to allow additional hunters to access their land. Finally, in the fourth section respondents were asked to provide demographic data about themselves.

Treatment. The audience was prepared for the discussion in two different ways. Two groups were presented with a 4-minute oral/visual presentation, which was immediately followed by the discussion session. During the presentation, respondents were showed photographs of in-field and farmstead shelterbelts and key distinguishing features of each were explained. The other two groups were first presented with a 15-minute video entitled "Windbreaks: An Agroforestry Practice" and produced by University of Missouri Center for Agroforestry that described functioning, benefits and management of in-field shelterbelts. The video was then followed with presentation of photographs of in-field and farmstead shelterbelts and the discussion session. The video "treatment" was introduced to examine if initial information on in-field shelterbelts has an influence on how agricultural producers value the in-field shelterbelts (Mitchell and Carson 1989).

Results and Discussion

Respondents' Demographics. A total of 47 respondents participated in the study; questionnaires of 45 participants were used for further statistical analysis. Agricultural producers were asked several questions regarding their gender, age, education, income, place of living and farm size. Respondents were primarly males (87%). Most respondents were of age 66 years or more (49%) and 46-55 years (27%). Respondents of 56-65 years and 36-45 years accounted for 15% and 9%, respectively. There were no agricultural producers younger than 35 years old. Most participants were high school graduates (41%) or college graduates (27%). About 76% of respondents lived on farms, whereas 7% lived in rural area, but not on a farm. Nearly 9% lived in towns with population of 10,001-50,000. A majority of agricultural producers operated farms smaller than 700 ac (under 300 ac - 61%; 301-700 ac - 25%). A relatively small number of producers operated farms larger than 700 ac (701-1100 ac - 9%; more than 1,100 ac - 5%). About 32% of participants reported one person working full-time on farm, whereas 16% indicated two persons. And 52% of respondents said no one worked full time on the farm. When asked for gross income in 2003, 91% of respondent reported income less than $120,000 (less than $39,999 - 25%; $40,000-$79,000 - 45%; $80,000-$120,000 - 21%); gross income of 9% of participants was greater than $120,000.

Shelterbelt ownership and condition. Most respondents (77%) indicated that in-field shelterbelts were present on their land in 2004. Out of those who did not have any in-field shelterbelts (23%), more than one-half had farmstead shelterbelts. Agricultural producers most often had two (31%) and one in-field shelterbelt (27%) on their land. Those who had three or four shelterbelts accounted for 15% each, and those with five or more in-field shelterbelts constituted 12%.

Agricultural producers were asked to provide some information on their most recently established in-field shelterbelt. If they did not have any in-field shelterbelt on their land, they were asked to provide information about the one that they were most knowledgeable about.

Most in-field shelterbelts (58%) were rather young (10 years or less). In-field shelterbelts of age in the range 11-20 years and 21-30 years accounted for 17% and 15%, respectively. Older in-field shelterbelts constituted 10%. Respondents reported that the most recent in-field shelterbelts were either in excellent or good condition (71%), whereas 11% indicated a medium condition. About 10% of in-field shelterbelts were in poor and 8% in very poor condition. On average, the "most recent in-field shelterbelt" was 1,000 ft long, rather wide (109 ft) and had more than five rows (47%). Three-row and five-row in-field shelterbelts accounted for 21% and 13%, respectively. One-row and two-row in-field shelterbelts, on the other hand, accounted for 11% and 5%, correspondingly. Four-row shelterbelts accounted only for 3%. Agricultural producers tended to plant trees mixed with shrubs (78%) in their in-field shelterbelts. Tree-only shelterbelts accounted for 22%. On average, an in-field shelterbelt had four tree and two shrubs rows. In a majority of the cases in-field shelterbelts were planted with hardwoods mixed with conifers (57%). Conifers-only and hardwoods-only in-field shelterbelts accounted for 26% and 17%, respectively. Most respondent (59%) planted in-field shelterbelts themselves.

Attitudes toward assistance programs. About 73% of respondents said that they obtained some form of governmental assistance to plant their in-field shelterbelts. Of those who did not receive any assistance, 17% reported that they were aware of the program, but not interested, whereas 83% indicated that they believed that there was no assistance program available in their area.

When asked if they would be interested in governmental and non-governmental assistance, 80% of respondents said that they would be interested in government-sponsored programs, whereas 42% would be in interested in non-governmental ones (percentages exceed 100% because respondents could say yes to both questions). There was strong evidence that agricultural producers were more likely to enroll in government-sponsored programs. However, respondents indicated from the discussion that they preferred these programs to offer more flexibility.

Agricultural producers were asked about the preferred method of providing them with information on establishment and management of in-field shelterbelts. More than half (about 60%) responded that they preferred to be contacted by program specialists, participate in workshops, and be sent a brochure. More than a third (34%) preferred to be able to access an Internet website with necessary and desired information, whereas 25% of respondents wanted to be sent a video. About 11% of respondents indicated that they would prefer other forms of communication (field days, hands-on cases, and e-mail). Respondents emphasized from the discussion that hands-on demonstration of successful shelterbelt designs were particularly effective in convincing undecided landowners to adopt in-field shelterbelts.

Attitudes toward hunting. Almost 87% of respondents said they had been approached by individual hunters asking them to allow hunting on their land. However, none of the respondents had been approached by a hunter association. About 95% of agricultural producers allowed some form of hunting on their land. Around 63% of respondents hunted their land themselves and/or with family members, whereas 61% allowed hunting by friends and neighbors. About 42% allowed free hunting to anyone; none of the respondents charged a fee for hunting (percentages exceed 100% because respondents were allowed to provide multiple responses).

When thinking about providing wildlife habitat for hunting, it is crucial to recognize the land features that are desired by hunters (Cable and Cook, 1990). Agricultural producers were asked to rank the importance of four land features for hunting using a arising scale from 1 (very low) to 5 (very high). As seen in Table 1, diversity of adjacent crops, close proximity to forest patches, presence of trees, and close proximity to water were indicated as highly important (4 on 1-5 scale) by most respondents (47%, 43%, 35% and 33%, respectively). Spatial continuity and size of the habitat were additional important factors as revealed during the discussion.

Agricultural producers were asked to evaluate the potential for developing a market for hunting on lands associated with in-field shelterbelts. More than one-half of respondents (55%) indicated that there was a potential for developing such a market, whereas 37% believed that there was no potential. About 8% of respondents were unsure. Of those who believed that there was potential for developing market for hunting, 55% rated the potential as weak and 45% indicated a moderate potential. None of respondents indicated a strong potential. None of the respondents who did not allow hunting believed that there was potential for a fee hunting market.

The issue of fee hunting was particularly controversial to agricultural producers, which was apparent during the discussion. Many of respondents indicated that although they see some potential for developing fee hunting market on lands associated with in-field shelterbelts, they would opt to not charge any fee. They explained that providing free access to their lands was part of local tradition and was considered good stewardship. Further, some respondents were concerned that introducing fee for hunting privileges may exclude, in the future, local hunters who would not be able to afford rising fees. Agricultural producers, however, would like to be able to control who hunts and on their lands and when. Trespassing was mentioned as an increasing nuisance problem that violated their property rights and posed safety hazards. Some respondents indicated that if fee hunting was to be successful, a more coordinated effort was required to provide network of shelterbelts that would constitute more diverse and desired wildlife habitat.

As desirability of wildlife habitat by hunters and level of expenditures associated with hunting is related to diversity of game species, it is crucial to know what species can potentially be hunted on lands associated with in-field shelterbelts. In terms of game wildlife that can be potentially hunted, agricultural producers most commonly mentioned deer, pheasant, rabbit, coyote, and raccoon (44%, 37%, 35%, 30% and 30%, respectively). Other game species commonly indicated included wild turkey, fox, squirrel, opossum, and goose, in decreasing frequency.

Opinions on importance of expected benefits and costs of in-field shelterbelts. Adoption of in-field shelterbelt technology and its dissemination depends, to a large extent, on how landowners perceive expected shelterbelt benefits and costs. Understanding which benefits are valued the most and which costs/negative effects create the most burden to landowners is crucial in designing successful assistance programs and capturing market potential. Agricultural producers were asked to indicate importance of selected shelterbelt benefits on a rising scale from 1 (very low) to 5 (very high). The importance of each benefit was assessed based on its mean value (Table 2). Soil erosion reduction and game wildlife habitat were ranked as highly important benefits (each with mean of 4.4). Respondents indicate from the discussion that reduction of soil erosion was the most common reason for planting their in-field shelterbelts and that over time they expected a positive influence on soil stabilization. Habitat for non-game wildlife and aesthetics were somewhat less important benefits (each with mean of 4.1). Finally, the producers assigned a medium importance to snow distribution (3.4), crop yield increase (2.8), and wood products (2.6), and a low importance to livestock protection (2.4).

In addition to expected benefits, respondents were asked to rank on the same scale the importance of selected costs and negative effects associated with in-field shelterbelts. On average, respondents assigned a medium or high importance to all costs and negative effects, except "shelterbelts attracting harmful pests that can damage adjacent crop" that received a low importance ranking (2.2) (Table 3). It seems that agricultural producers are particularly concerned with management and start-up costs. Of the considered costs and negative effects, only "maintenance is too costly/time consuming" and "high start-up costs" were ranked as highly important costs (3.8 and 3.7, respectively). From the discussion session, respondents indicated that the two first years were most difficult both in terms of finances, management, and shelterbelt survival. Interestingly, land taken out of production was, on average, of lower importance (3.1 - medium). Other examined costs and negative effects included, interference with farm operations, attracting nuisance wildlife, competition with adjacent crops, high costs of future shelterbelt removal, and too much hassle. All had medium importance with mean values of 3.0, 3.0, 2.8, 2.6 and 2.6, respectively.

A two-tailed t-test was conducted to examine if respondents who were presented with the video on in-field shelterbelts differed in assigning importance ranking to benefits and costs from those who were not presented with the video. There was no statistical difference in the ranking of the benefits between the two groups. However, the two groups differed in importance ranking of some costs. Those who were not presented with the informational video assigned, on average, a higher importance to "too much hassle" (3.0 vs. 2.1), "maintenance too costly/time consuming" (4.1 vs. 3.5) and "high costs of future shelterbelt removal" (3.2 vs. 2.1). There was indication of difference at p=0.04, p=0.08 and p=0.03, respectively, for the three "costs".

Interestingly, respondents differed significantly in assigning importance ranking when the presence of in-field shelterbelts was taken into account. Those who own one (or more) in-field shelterbelt in 2004 tended, on average, to assign lower importance values. The difference was significant for the following benefits and costs: livestock protection (2.1 vs. 3.4, p=0.04), habitat for game wildlife (4.3 vs. 4.8, p=0.09), wood products (2.4 vs. 3.3, p=0.11), land taken out of production (3.0 vs. 3.9, p=0.09), competition with adjacent crops (2.6 vs. 3.5, p=0.06), interference with farm operations (2.8 vs. 3.7, p=0.07), too much hassle (2.4 vs. 3.4, p=0.04), shelterbelts attract nuisance wildlife (2.7 vs. 3.8, p=0.07), and high start-up costs (3.6 vs. 4.4, p=0.06). One plausible explanation is that agricultural producers who did not own in-field shelterbelts had limited experience with potential benefits and costs, and, therefore, their expectations were inflated. However, for the producers who had in-field shelterbelts the assessment was more pragmatic as they used factual costs and were more realistic in terms of expected benefits.

Those who had an in-field shelterbelt in 2004 also indicated more often that shelterbelt benefits out weighed the costs (p=0.04).

Agricultural producers have to commit significant financial resources to plant in-field shelterbelts and remove land from agricultural production, so the likelihood of planting in-field shelterbelts depends on whether the expected benefits (monetary and non-monetary) exceed the costs. A majority of respondents believed that benefits of in-field shelterbelts out weighed the associated costs (57%). About 33% of respondents believed that the benefits might be greater than the costs, whereas 5% were uncertain. Only 5% of respondents believed that costs associated with in-field shelterbelts were greater than the benefits. Responses of those who were presented with the video and were not did not differ.

From the discussion, agricultural producers revealed that their assessment was rather heuristic than based on economic analysis. They indicated the need for more specific information that would help them to quantify/project expected benefits over time. The producers indicated also that long-term benefits were more apparent to them than short-term ones. Some agricultural producers indicated also that planting in-field shelterbelts helped to manage their marginal lands, on which crop production was economically not effective. In such a case, in-field shelterbelts helped to preserve the land and provided long-term farm improvement.

Opinions of agricultural producers on hunting on lands adjacent to in-field shelterbelts. Willingness of agricultural producers to provide a wildlife habitat to hunters is influenced significantly by their knowledge and opinions of hunting. When deciding on whether to allow hunting, either free or fee hunting, landowners weigh expected benefits against costs or negative consequences. Historical and social considerations play an important role in making such decisions for many landowners (Smith et al. 1992). Respondents were asked to value the importance of 12 features of hunting that included six potential benefits: additional income, increase in land value, better stewardship, economic opportunities for local community, enjoyment/recreation and decreased damage by reducing population of nuisance wildlife and six negative consequences: potential liability, hunters' misconduct, trespassing, personal safety, hunters' damage to crops and interference with farm operations.

The importance of the features was assessed on a rising 5-point scale. On average, respondents indicated that hunting was not very important in generating an additional income (mean of 1.9 – low importance). A majority of agricultural producers (51%) were convinced that the importance of hunting in providing an additional income was very low (1 on 1-5 scale) and only 7% thought it was very high (5 on 1-5 scale).

Respondents, however, assigned a higher importance to hunting in increasing land value and providing economic opportunities to local community. On average, they assigned medium importance to both features (2.7 and 2.6). About 10% of respondents indicated that hunting was highly important in increasing value of the land and only 5% indicated it was very important in creating economic opportunities for local community. However, there were a relatively larger number of respondents who critically assessed both features as very low importance – 24% and 19%, respectively. Interestingly, those who believed that there was a weak and moderate potential for fee hunting on lands associated with in-field shelterbelts assigned higher mean importance ranking to "hunting provides additional income" (2.1 vs. 1.5) and "hunting provides economic opportunities for local community" (2.9 vs. 2.1). The differences were significant at p=0.06 and p=0.05, respectively (two-tailed t test).

Agricultural producers recognize, however, the importance of hunting in providing intangible benefits, such as enjoyment and recreation for landowner and her/his family, and better stewardship. On average, they indicated that both features were highly important (mean values of 4.2 and 3.8, respectively). Many respondents assigned a very high importance to both benefits, 52% and 38%, respectively.

Research indicates that negative consequences of hunting influence landowner's approval of hunting (Applegate 1984). In this study, when asked to assign importance ranking, respondents believed that trespassing and hunter misconduct were the most important – both were assigned a high importance (mean values of 4.0 and 3.5, respectively). About 75% of the respondents indicated that trespassing was a highly or very highly important issue, whereas 51% though the same about hunters' misconduct.

Agricultural producers believed that potential liability for user injuries, concern with personal safety, and damage to crops caused by hunters were of medium importance (mean values of 3.3, 3.2 and 2.7, respectively), whereas hunter interference with farm operations was of low importance (2.2).

Willingness of agricultural producers to provide wildlife habitat for hunting. In some states, such as Iowa, hunting on private lands is traditionally free of charge. Hunters interested in hunting on somebody's land, however, need to ask a landowner for permission to do so. Because hunting privileges are not traded on the market, it is difficult to establish the full economic value associated with hunting. Consequently, it is challenging to make managerial decisions regarding provision of wildlife habitat both for individual landowner and at the state level.

Contingent Valuation (CV) is a method used to reveal the value people place on goods and services that traditionally are not traded in markets, such as clean air and water, hunting, and aesthetics (Freeman, 1993; Pearse 1990). A hypothetical market is described to individuals who are then asked to state the maximum amount of money they are willing to pay (WTP) for the good or service in question, or minimum amount of money are they willing to accept (WTA) to forgo such a good or service (Freeman, 1993, Haab and McConnell, 2002).

In this study, CV was used to elicit respondents' willingness to provide hunters with access to wildlife habitat associated with in-field shelterbelts at various threshold prices. In the questionnaire a set of questions was used to describe a hypothetical situation, in which respondents assumed that they owned a 12-year old in-field shelterbelt. Description included model photographs of the shelterbelt. Respondents were informed that the shelterbelt was designed to provide multiple benefits, including habitat for pheasants. Agricultural producers were then asked about their willingness to allow additional pheasant hunters on their land via the following WTA question: "How much monetary compensation would you need to grant hunting rights to hunt pheasants on your land?" A payment card format (Boyle, 2003) was used to elicit amounts of compensation needed. Respondents were presented with eights compensation levels: $0, $10, $30, $50, $70, $90, $110 and more than $110 (per visit per party of hunters). Respondents were asked to select only one level of compensation and indicate the number of hunters in a party that they would allow to access their land at a time. The visit was specified as any part of the day that the respondent arranged with hunter/hunters to hunt on her/his land in association with the in-field shelterbelts.

A majority of respondents (78%) required compensation of $50 or less (Table 6). Out of that, 33% of respondents did not require any compensation. A relatively small number of respondents (4%) indicated that they would not allow hunting at all. About 10% of respondents indicated compensation of $110, whereas 5% reported required compensation of $70. About 3% of agricultural producers specified a required compensation at $90.

The mean WTA compensation value was $29.75 per visit per party, whereas a median value was $10.00 per visit per party. On average, agricultural producers would allow four hunters in a party at a time. Interestingly, those who owned an in-field shelterbelt in

2004, on average, required compensation more than twice as much (\$35.86) as those who did not own an infield shelterbelt (\$15.00) – different at p=0.12 (two-tailed t-test).

Regression analysis. A linear regression model was used to predict an amount of minimum monetary compensation required (WTA) by agricultural producers for allowing additional hunters to access their land associated with in-field shelterbelts to hunt pheasants. Nineteen explanatory variables, believed to have a significant influence on respondents' WTA, were selected *a priori* for testing. The variables were divided into sets (Table 7 and 8). The first set includes socioeconomic variables and those related to in-field shelterbelts, such as presence of in-field shelterbelt (PRES) – dummy variable, financial assistance (ASSIST) – dummy variable, hunting potential (HUNTPOT) – dummy variable, education (EDUC), income (INC), place of living (LIVP) and farm size (FARM). The second set included variables representing attitudes of agricultural producers toward positive and negative consequences of hunting and includes additional income (ADDINC), land value increase (INLAND), better stewardship (STEW), economic opportunities for local community (ECOPP), liability (LIA), hunters' misconduct (MISC), trespassing (TRESP), personal safety (PSAF), damage to crops by hunters (CROPH), decreased damage to crops due reduced nuisance wildlife (DECROP) and interference of hunters with farm operations (INTF).

The WTA was regressed separately on each set of explanatory variables by using the following regression equation:

$$WTA = \beta_0 + \sum_{i=1}^{J} \beta_i X_i$$

where:

WTA – willingness to accept – a compensation that agricultural producers would require to allow additional hunters to hunt pheasants on lands associated with in-field shelterbelts (in dollars per visit per party of hunters).
β_0 – constant
β_i – coefficient associated with explanatory variable X_i
X_i – explanatory variable (see Table 6 and 7 for description of examined explanatory variables)

Five models with different specifications were tested for the first set of variables to assess predictability of the WTA based on socioeconomic variables. Examination of Table 9 reveals that socioeconomic variables did not offer good predictability of the WTA. When all the variables were included in the regression (Model 1), none of them were statistically significant. Similarly, in Model 3 where hunting potential (HUNTPOT) and later place of living (LIVP) and farm size (FARM) were excluded, the remaining variables were statistically insignificant. In Model 4, however, presence of shelterbelt (PRES) was significant at p=0.11. Nevertheless, this variable is sensitive to model specifications (see models 1-4). The coefficient associated with PRES in this model indicates that if shelterbelt was present in 2004 on agricultural land, the producer would require an additional $22.94 per visit per party of hunters to allow them hunting on land associated with an in-field shelterbelt. Model 5, in which WTA was regressed only on income (INC) and place of living (LIVP) did not reveal any statistical significant variable.

It was assumed that attitudes toward positive and negative consequences of hunting might have greater influence on WTA. An assessment of Table 10 shows that attitude variables indeed offer a better predictability of WTA. Four models were tested to assess robustness of the explanatory variables. In Model 1, in which all attitude variables were used to predict WTA, only additional income (ADDINC) was found to be significant at p=0.11. The ADDINC continued to be statistically significant at p=~0.00 in Model 2, 3 and 4 and was robust to model specifications. ADDINC had, as expected, a positive sign, meaning that agricultural producers who assign a higher importance ranking to hunting in generating additional income will also require a higher compensation. For each unit increase on the 1-5 ranking scale, the required compensation (WTA) will increase by $20.98 per visit per party of hunters (Model 4).

Trespassing (TRESP) was statistically significant in Model 2, 3 and 4 (p=0.04). Personal safety (SAFT), on the other hand, was significant, but at p=0.16 in the best model. Interestingly, TRESP and SAFT had negative signs and this was not expected. Agricultural producers who were concerned with trespassing and personal safety and assigned higher importance ranking to them would require lower compensation. It is believed that this is due to the common belief among surveyed producers that hunting should be free of charge. Nearly 40% of respondents indicated that they would not charge any fee for allowing additional hunters on their land and a large proportion of these respondents assigned a high or very high importance to trespassing and personal safety. The WTA will be lower for each unit increase on 1-5 ranking scale by $11.96 and $6.44 per visit per party of hunters for trespassing and personal safety, respectively.

Summary and Conclusions

Although the results of this study cannot be generalized to the overall population of agricultural producers in Northeastern Iowa, they provide very interesting and useful insights regarding the potential for generating income based on hunting on lands adjacent to and within in-field shelterbelts. The study also reveals levels of importance of selected benefits, costs and negative effects of in-field shelterbelts and hunting.

Results show that agricultural producers who had in-field shelterbelts were aware of government assistance programs and most of them obtained it in some form (73%). Results also show that in the future they were more likely to use government-sponsored assistance relative to non-governmental programs. A majority of respondents (60%) preferred traditional methods of communication, such as be contacted by a program specialist, participate in workshops or be sent a brochure, when seeking information about in-field shelterbelts. However, there is also a significant number of producers (34%) who were interested in non-traditional methods of communication, such as the Internet. This might be an excellent opportunity for agencies to reach out to a greater number of landowners in a more cost effective way and make information at the same readily accessible.

The study shows that agricultural producers have very extensive experience with hunting and are well aware of associated benefits and negative effects. Nearly 87% of producers reported that they had been asked by hunters for permission to hunt on their land in the past. Nearly all agricultural producers (91%) allowed some form of hunting on their land. In most cases hunting was practiced by themselves and/or family members. Friends and neighbors also accounted for a significant group (61%) of hunters on the respondents shelterbelt. Slightly less than half of the agricultural producers allowed anyone to hunt, but no one charged a fee for it. Agricultural producers recognized that presence of trees, close proximity to forest patches and water sources, and diversity of adjacent crops play a vital role in making a wildlife habitat more attractive for hunting; on average they ranked them as highly important.

It seems that agricultural producers value in-field shelterbelts the most for soil erosion reduction, habitat for game and non-game, and aesthetics. The video presentation did not introduce any significant differences in respondents' ranking of examined benefits. However, it influenced how respondents ranked some costs. Significant differences were observed for "too much hassle", "maintenance too costly/time consuming" and "high costs of future shelterbelt removal". Those who were not presented with the video ranked these costs higher.

Although none of the respondents charged a fee for hunting, more than half believed that there is a potential for developing a fee hunting market. However, 55% believed that the potential was weak, whereas 45% believed the potential was moderate. None of the respondents indicated a strong potential. Consequently, agricultural producers, overall, believed that the likelihood of generating additional income from hunting was moderate to low. However, those who indicated a potential for fee hunting also assigned a greater importance ranking to hunting in generating additional income and providing economic opportunities for local community, although hunting was somewhat important for increasing land value and providing economic opportunities to the local community. Agricultural producers valued highly the intangible benefits associated with hunting, such as enjoyment/recreation and better stewardship.

The mean required compensation (WTA) by agricultural producers for granting hunting privileges requested was $22.94 per visit per party of four hunters. Ownership of an in-field shelterbelts had a significant influence on the required amount of compensation. Those who had an in-field shelterbelt required more than twice the WTA ($35.86) than those who do not own one ($15.00). A significant number of producers believed that hunting should remain free (33%). However, those who wanted to be compensated and those who did not, express a strong need for controlling the number of hunters accessing their land at the time.

On average, agricultural producers were convinced that the benefits of in-field shelterbelts out weighed associated costs. However, they varied in assessing the importance of particular benefits and costs. Soil erosion reduction was valued as the most important benefit, which is consistent with reports in the literature and the fact that soil erosion caused by wind is a significant problem in the area, according to respondents. Interestingly, habitat for game wildlife was equally important, whereas habitat for non-game wildlife and aesthetics were slightly less important. Crop yield increase, livestock protection, and wood products were assigned a medium importance.

In terms of costs and negative effects, it seems that agricultural producers were concerned the most with maintenance and time needed for it and with high start up costs. Other reported negative effects, such as land taken out of crop production, interference with farm operations, and competition with adjacent costs, were thought to be medium important. Respondents who were presented with video on in-field shelterbelts provided importance ranking to "too much hassle", "maintenance too costly/time consuming" and "high costs of future shelterbelt removal" that were different from those who weren't presented with the video. On average, they rank them as less important.

Acknowledgements

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Table 1. Importance of four land features in providing quality habitat desired by hunters based on responses of 45 agricultural producers surveyed in Northeastern Iowa, 2004. Numbers represent relative frequencies except mean, confidence interval and number of responses.

Land Feature	**Importance of the feature**						Mean Rank[a]	95% CI[b] for mean rank		n[c]
	Very Low	Low	Medium	High	Very High	Unsure				
	1	2	3	4	5			Lower	Upper	
Close proximity to forest patches	2	1	8	16	9	1	3.8	3.5	4.2	37
Close proximity to water	2	5	4	12	13	0	3.8	3.4	4.2	36
Presence of trees	2	3	11	15	11	1	3.7	3.4	4.1	43
Diversity of adjacent crops	3	2	6	18	5	4	3.6	3.2	4.0	38

[a] Responses of unsure respondents were excluded when calculating the mean rank for each benefit
[b] Confidence interval for mean
[c] n varies due to non-responses

Table 2. Importance of expected shelterbelt benefits reported by 45 agricultural producers surveyed in Northeastern Iowa, 2004. Numbers represent percentage relative frequencies.

Expected Shelterbelt Benefits	**Importance of Benefit**						Mean Rank[a]	95% CI[b] for mean rank		**n[c]**
	Very Low	Low	Medium	High	Very High	Unsure				
	1	2	3	4	5			lower	upper	
Soil erosion reduction	1	1	2	16	25	0	4.4	4.1	4.7	45
Habitat for game wildlife	1	0	3	17	24	0	4.4	4.2	4.6	45
Habitat for non-game wildlife	1	2	8	12	19	0	4.1	3.8	4.4	42
Improved aesthetics	2	1	6	13	17	0	4.1	3.7	4.4	39
Snow distribution across adjacent agricultural field	3	6	13	8	11	0	3.4	3.1	3.8	41
Yield increase	7	10	7	8	5	4	2.8	2.4	3.3	41
Wood products, such as firewood, posts and poles	14	8	9	3	8	1	2.6	2.1	3.1	43
Livestock protection	16	3	2	9	3	4	2.4	1.9	2.9	37

[a] Responses of unsure respondents were excluded when calculating the mean rank for each benefit
[b] Confidence interval for mean
[c] n varies due to non-responses

Table 3. Importance of expected shelterbelt costs and negative effects reported by 45 agricultural producers surveyed in Northeastern Iowa, 2004. Numbers represent percentage relative frequencies.

Expected Shelterbelt Benefits	**Importance of Benefit**						Mean Rank[a]	95% CI[b] for mean rank		n[c]
	Very Low	Low	Medium	High	Very High	Unsure				
	1	2	3	4	5			lower	upper	
Maintenance is costly/time consuming	2	3	12	11	15	0	3.8	3.4	4.1	43
High start-up costs	2	6	9	9	16	0	3.7	3.4	4.1	42
Land is taken out of production	9	7	8	7	12	0	3.1	2.7	3.6	43
Interference with farm operations	8	7	12	9	6	0	3.0	2.6	3.4	42
Shelterbelts attract nuisance wildlife that can damage adjacent crops	9	8	8	10	7	1	3.0	2.5	3.4	43
Competition with adjacent crops	8	9	12	9	3	0	2.8	2.4	3.1	41
High costs associated with future shelterbelt removal	13	6	6	6	6	4	2.6	2.1	3.1	41
Too much hassle	13	7	14	3	6	0	2.6	2.2	3.0	43
Shelterbelts attract harmful pests that can damage adjacent crops	11	18	7	4	1	2	2.2	1.9	2.5	43

[a] Responses of unsure respondents were excluded when calculating the mean rank for each benefit
[b] Confidence interval for mean
[c] n varies due to non-responses

Table 4. Importance of benefits associated with hunting reported by 45 agricultural producers surveyed in Northeastern Iowa, 2004. Numbers represent relative frequencies.

Expected Shelterbelt Benefits	Importance of Benefit: Very Low	Low	Medium	High	Very High	Unsure	Mean Rank[a]	95% CI[b] for mean rank		n[c]
	1	2	3	4	5			lower	upper	
Provides enjoyment/recreation to me and my family	2	0	9	10	23	0	4.2	3.9	4.5	44
Shows a better stewardship of the land	1	6	9	10	16	0	3.8	3.4	4.2	42
Increase value of the land	10	9	10	8	4	1	2.7	2.3	3.1	42
Provides economic opportunities for local community	8	14	7	10	2	1	2.6	2.2	3.0	42
Provides an additional income	22	9	9	0	3	0	1.9	1.6	2.3	43

[a] Responses of unsure respondents were excluded when calculating the mean rank for each benefit
[b] Confidence interval for mean
[c] n varies due to non-responses

Table 5. Importance of negative consequences of hunting reported by 45 agricultural producers surveyed in Northeastern Iowa, 2004. Numbers represent percentage relative frequencies.

Expected Shelterbelt Benefits	**Importance of Negative Consequences**						Mean Rank[a]	95% CI[b] for mean rank		**n[c]**
	Very Low	Low	Medium	High	Very High	Unsure				
	1	2	3	4	5			lower	upper	
Trespassing	2	4	4	18	15	1	4.0	3.6	4.3	44
Hunters' misconducts	3	7	10	12	10	1	3.5	3.1	3.8	43
Potential liability for user's injuries	5	10	6	7	13	1	3.3	2.9	3.8	42
Personal Safety	4	7	15	6	8	2	3.2	2.8	3.6	42
Decrease damage to crops by reducing nuisance wildlife	2	8	14	6	4	2	3.1	2.7	3.4	36
Damage to crops by hunters	9	10	13	7	4	1	2.7	2.3	3.1	44
Presence of hunters will interfere with my farm operations	11	18	8	2	3	1	2.2	1.9	2.6	43

[a] Responses of unsure respondents were excluded when calculating the mean rank for each benefit
[b] Confidence interval for mean
[c] n varies due to non-responses

Table 6. Minimum monetary compensation (WTA) required by surveyed agricultural producers for allowing additional hunters to access land to hunt pheasants, Northeastern Iowa, 2004.

WTA	Number of agricultural producers	Mean number of hunters in a party that producers will allow to access their land
\$0	13	4
\$10	7	4
\$30	5	3
\$50	6	4
\$70	2	4
\$90	1	3
\$110	4	6
>\$110	0	

Table 7. Definitions and descriptive statistics of socioeconomic explanatory variables used to predict WTA based on responses of 45 agricultural producers surveyed in Northeastern Iowa in 2004.

Socioeconomic Variable	Description	Mean	SD
ASSIST	Financial assistance. 1 when financial assistance was obtained to plant the most recent in-field shelterbelt, 0 otherwise	0.7	0.5
EDUC	Education. 1 – some high school or less, 2 – high school graduate, 3 – vocational or technical diploma or certificate, 3 – some college, 4 –college graduate (Bachelor's Degree), 4 – advanced college graduate (Master's Degree, Ph.D. or other)	3.4	1.4
FARM	Farm size in 2004. 1 for less than 300 ac, 2 for 301-700 ac, 3 for 701-1,100 ac and 4 for more than 1,100 ac.	1.6	0.8
HUNTPOT	Potential for developing fee hunting market. 1 for yes, 0 otherwise.	0.6	0.5
INC	Gross income in 2003. 1 – less than $39,999, 2 - $40,000-$79,999, 3 - $80,000-$120,000, 4 – more than $120,000	2.1	0.9
LIVP	Place of living. 1 for rural (living on farm or in rural area but not of farm and 0 for urban (in town or in a city).	0.2	0.4
PRES	Shelterbelt presence in 2004. 1 for yes and 0 for no.	0.8	0.4

Table 8. Definitions and descriptive statistics of attitudinal explanatory variables used to predict WTA based on responses of 45 agricultural producers surveyed in Northeastern Iowa in 2004. Variables represent features and consequences of hunting ranked on scale from 1 (very low importance) to 5 (very high importance).

Attitudinal Variable	**Description**	**Mean**	**SD**
ADDINC	Additional income	1.91	1.17
CROPH	Damage to crops by hunters	2.70	1.25
DECROP	Decreases damage to crops by reducing nuisance wildlife	3.06	1.07
ECOPP	Provides economic opportunities for the local communities	2.61	1.20
ENJREC	Provides enjoyment/recreation to me and family	4.18	1.06
INLAND	Increases value of the land	2.68	1.31
INTF	Presence of hunters will interfere with farm operations	2.24	1.12
LIA	Liability	3.32	1.46
MISC	Hunters' misconduct	3.45	1.23
PSAF	Personal safety	3.18	1.24
STEW	Shows better stewardship	3.81	1.17
TRESP	Trespassing	3.93	1.12

Table 9. Results from regressing WTA on socioeconomic explanatory variables. Based on responses of 45 agricultural producers surveyed in Northeastern Iowa, 2004.

Explanatory Variable	Model 1	Model 2	Model 3	Model 4	Model 5
CONSTANT	-18.05	-5.70	-3.03	-0.79	6.95
	(0.58[a])	(0.86)	(0.92)	(0.98)	(0.77)
PRES	11.28	22.42	16.36	22.79	
	(0.58)	(0.26)	(0.37)	(0.11)	
ASSIST	-3.12	-9.81	-13.33		-13.22
	(0.86)	(0.57)	(0.42)		(0.40)
HUNTPOT	-0.34				
	(0.98)				
EDUC	6.54	2.12	4.40	1.75	5.85
	(0.26)	(0.71)	(0.40)	(0.70)	(0.23)
INC	5.17	2.44	7.13	4.46	6.23
	(0.59)	(0.80)	(0.39)	(0.52)	(0.40)
LIVP	15.65	16.90			
	(0.45)	(0.43)			
FARM	2.59	7.78			
	(0.83)	(0.46)			
R^2	0.17	0.12	0.08	0.10	0.03

[a] numbers in brackets represent a significance level

Table 10. Results from regressing WTA on attitude variables. Based on responses of 45 agricultural producers surveyed in Northeastern Iowa, 2004.

Explanatory Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
CONSTANT	107.20	71.33	76.65	57.44
	(0.05[a])	(0.01)	(~0.00)	(~0.00)
ADDINC	19.17	19.17	20.789	20.98
	(0.11)	(~0.00)	(~0.00)	(~0.00)
INLAND	4.94	4.86		
	(0.56)	(0.23)		
STEW	2.19			
	(0.81)			
ECOPP	1.49			
	(0.90)			
ENJREC	-13.76	-5.87	-5.15	
	(0.15)	(0.17)	(0.20)	
LIA	0.20			
	(0.98)			
MISC	-0.51	4.00		
	(0.97)	(0.57)		
TRESP	-16.23	-15.14	-11.64	-11.96
	(0.20)	(0.04)	(0.02)	(0.02)
SAFT	-11.39	-6.61	-6.04	-6.44
	(0.34)	(0.19)	(0.18)	(0.16)
CROPD	-1.96			
	(0.88)			
DECROPD	8.73			
	(0.46)			
INTF	1.15			
	(0.92)			
R^2	0.59	0.56	0.52	0.49

[a] numbers in brackets represent a significance level

Appendix. Questionnaire Instrument.

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Shelterbelts Survey

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Farmers

September 2004

This survey is completely confidential. We know you value your privacy, and therefore we assure you complete confidentiality. We ask you to fill out this questionnaire anonymously, so your name will not be linked to your responses. Moreover, information provided by you will be used for research purposes only. We will use only aggregated responses in our reports, so there is no way to trace back to your individual response.

Please, read questions carefully before providing your response. When suggested responses are provided, select the one that describes your situation the best. Please, use ☒ or ☑ to indicate your answer.

It will take about 20 minutes to complete this questionnaire.

In-field shelterbelts ...

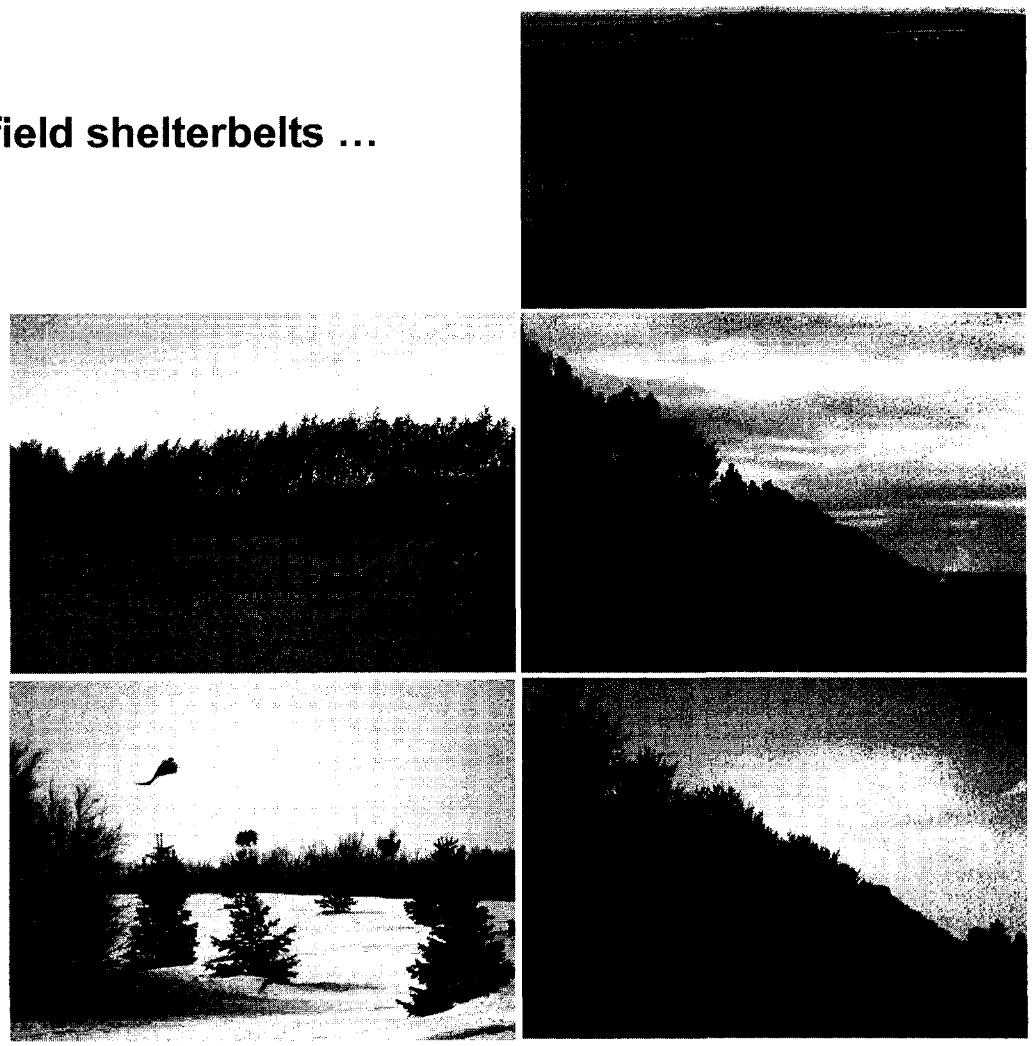

Photo courtesy of USDA Department of Natural Resources Conservation

- Shelterbelts, also known as windbreaks, have been present in the Midwestern landscape for decades. They are composed of one or more rows of trees and/or shrubs. They may contain only evergreens (conifers), only hardwoods, a mixture of evergreens and hardwoods, and sometimes a row of shrubs or only shrubs.
- They are known to provide many benefits, including increased crop yield, reduced soil erosion, livestock protection, and increased upland game.
- Shelterbelts that protect crop fields are called in-field shelterbelts as compared to ones that are planted around out-buildings, which are called windbreaks. In-field shelterbelts are established along agricultural field edges or interior. They shelter annual crop and hay/pasture fields from wind.

In this survey we ask for your opinions regarding in-field shelterbelts, information about any in-field shelterbelt that you may have on your land, and your preferences about assistance programs for establishing in-field shelterbelts and hunting on agricultural land adjacent to them.

1

In this part of the questionnaire we would like to ask you questions about your opinions about in-field shelterbelts, reasons why you may have shelterbelts on your agricultural land or why not, and your preference regarding assistance programs for in-field shelterbelts.

1. Are there any ***in-field shelterbelts*** present on the land that you currently (2004) own or rent? Please check any boxes that are true.

- ❑ Yes
- ❑ No ⟶ *Please check all that apply:*
  - ❑ I have some farmstead windbreak(s) around my homestead and/or agricultural buildings (please go to a text box on top of page 4)
  - ❑ There were some in-field shelterbelts on the land that I previously owned or rented (please go to a text box on top of page 4)
  - ❑ I don't have any shelterbelts (please go to a text box on top of page 4)

2. How many shelterbelts are located adjacent to and/or inside agricultural land that you own and/or rent?

- ❑ 1
- ❑ 2
- ❑ 3
- ❑ 4
- ❑ 5 or more

3. Out of the number of shelterbelts that you indicated in question 2, how many of them are located on agricultural land that you rent ***to*** someone else?

- ❑ 0
- ❑ 1
- ❑ 2
- ❑ 3
- ❑ 4
- ❑ 5 or more

4. Out of the number of shelterbelts that you indicated in question 2, how many of them are located on agricultural land that you rent ***from*** someone else?

- ❑ 0
- ❑ 1
- ❑ 2
- ❑ 3
- ❑ 4
- ❑ 5 or more

For questions 5 to 14 we ask that you think of the most recently established in-field shelterbelt on land that you own or rent or the shelterbelt that you are most knowledgeable about.

5. What is the approximate age of this shelterbelt?

- ❑ 10 years or less
- ❑ 11-20
- ❑ 21-30
- ❑ 31-40
- ❑ 41-50
- ❑ 51 or more years

6. In your opinion, what is the current condition of this in-field shelterbelt?

- ❑ Excellent. Trees look very healthy. More than 95% of trees originally planted survived.
- ❑ Good. Majority of trees look healthy. About 86-95% of trees originally planted survived.
- ❑ Medium. Trees look mostly healthy. About 76-85% of trees originally planted survived.
- ❑ Poor. Many trees look unhealthy and only 50-75% of trees originally planted survived.
- ❑ Very poor. Most trees look unhealthy. Less than 50% of trees originally planted survived.

7. How many rows does this shelterbelt have?

- ❑ 1
- ❑ 2
- ❑ 3
- ❑ 4
- ❑ 5
- ❑ more than 5 rows

8. What is the tree and shrub composition this shelterbelt?

- ❑ Trees
  Number of rows: __________
- ❑ Shrubs
  Number of rows: __________

9. If at least one row is trees, what is the general tree species composition of this shelterbelt? Skip to question 11 if no tree rows.

- ❑ Only hardwoods
- ❑ Only conifers (evergreens)
- ❑ Mix of hardwoods and conifers (evergreens)

10. What are the approximate dimensions of this shelterbelt?

Approximate length _____ feet Width _____ feet

11. Who planted this shelterbelt?

- ❑ I did (includes also hired labor)
- ❑ Previous owner
- ❑ Other ____________________

12. Did you or someone obtain any financial assistance (such as cost-share) from any governmental source to establish this shelterbelt? Please check all boxes that are true.

- ❑ Yes (please go to text box on the next page)
- ❑ No ⟶ *Please check all that apply:*
  - ❑ I was unaware of any assistance program
  - ❑ I was aware, but not interested in assistance programs
  - ❑ I was unsure whom to ask
  - ❑ I found no information available on such programs
  - ❑ I believe that there were no such program available in my area

13. Have you ever been approached by individual hunters or a hunters' association or both asking you to allow hunting on your land? Please check all that apply.

- ❑ No
- ❑ Yes ⟶ *Please check all that apply:*
  - ❑ Individual hunters have asked me.
  - ❑ I have been asked by a hunters' association

14. Do you currently allow hunting in and around your in-field shelterbelt? Please check all that apply.

- ☐ No
- ☐ Yes ⟶ *Please check all that apply:*
  - ☐ Only by myself and/or family members
  - ☐ Only by friends and neighbors
  - ☐ I allow free hunting
  - ☐ I charge a fee

15. In your opinion, how important are land features in attracting hunters in your area?

Land Feature	**Importance of the Feature**					
	Very Low				Very High	Unsure
	1	**2**	**3**	**4**	**5**	
Diversity of adjacent crops	☐	☐	☐	☐	☐	☐
Close proximity to forest patches	☐	☐	☐	☐	☐	☐
Presence of trees	☐	☐	☐	☐	☐	☐
Close proximity to water	☐	☐	☐	☐	☐	☐
Other ____________	☐	☐	☐	☐	☐	☐
Other ____________	☐	☐	☐	☐	☐	☐

2

In this section of the questionnaire, we would like to ask for your opinions about in-field shelterbelts in general.

16. Assume that you want to establish a new in-field shelterbelt. Then, would participating in a government-sponsored cost-share program, such as the continuous open-enrollment Conservation Reserve Program (CRP) be attractive to you?

- ❑ Yes
- ❑ Maybe
- ❑ No
- ❑ Uncertain

17. Would you be interested in participating in a non-governmental (NGO)-sponsored cost-share program perhaps offered by local chapters of Pheasants Forever or other local wildlife/resources groups?

- ❑ Yes
- ❑ Maybe
- ❑ No
- ❑ Uncertain

18. In your opinion, what method of communication is the best to provide you with information regarding establishment and care of an in-field shelterbelt? Check all that apply.

- ❑ Be contacted personally by a program specialist
- ❑ Participate in a workshop
- ❑ Be sent informational brochures
- ❑ Be sent an educational video
- ❑ Be able to access an Internet website that would provide necessary information
- ❑ Other ______________________________

19. In your opinion, what shelterbelt benefits do you expect to receive and how important are they? Please rank the benefits on a scale from 1 to 5, where 1 indicates very low importance and 5 indicates very high importance.

Expected Shelterbelt Benefit	**Importance of Benefit**					
	Very Low				Very High	Unsure
	1	**2**	**3**	**4**	**5**	
Yield increase for sheltered crop	❑	❑	❑	❑	❑	❑
Soil erosion reduction	❑	❑	❑	❑	❑	❑
Livestock protection	❑	❑	❑	❑	❑	❑
Habitat for game wildlife (birds, rabbits, etc.)	❑	❑	❑	❑	❑	❑
Habitat for non-game wildlife	❑	❑	❑	❑	❑	❑
Improved aesthetics	❑	❑	❑	❑	❑	❑
Snow distribution across adjacent agricultural field	❑	❑	❑	❑	❑	❑
Wood products, such as firewood, posts & poles	❑	❑	❑	❑	❑	❑
Other: ____________	❑	❑	❑	❑	❑	❑
Other: ____________	❑	❑	❑	❑	❑	❑

20. In your opinion what are the expected costs or negative effects of in-field shelterbelts?

Costs or Negative Effects	Importance of Cost or Negative Effect					
	Very Low				Very High	Unsure
	1	2	3	4	5	
Land is taken out of production	❑	❑	❑	❑	❑	❑
Competition with adjacent crops	❑	❑	❑	❑	❑	❑
Interference with farm operations	❑	❑	❑	❑	❑	❑
Too much hassle	❑	❑	❑	❑	❑	❑
Shelterbelts attract harmful pests that can damage adjacent crop	❑	❑	❑	❑	❑	❑
Shelterbelts attract nuisance wildlife that can damage adjacent crops	❑	❑	❑	❑	❑	❑
High start-up costs	❑	❑	❑	❑	❑	❑
Maintenance is costly/time consuming	❑	❑	❑	❑	❑	❑
High costs associated with future shelterbelt removal	❑	❑	❑	❑	❑	❑
Other ________________	❑	❑	❑	❑	❑	❑

21. In your opinion, do the in-field shelterbelt benefits out weight the costs?

❑ Yes
❑ Maybe
❑ No
❑ Uncertain

3

In this section, we would like to learn about your opinions towards hunting on land associated with in-field shelterbelts.

Assume that in-field shelterbelt system like the one of those presented in the pictures below was established on your land twelve years ago. The system was designed to provide multiple benefits, like crop yield increases, reduced soil erosion, snow distribution and suitable wildlife habitat – for game species such as pheasants.

Gaspar Horvath and Robert Grala, 2001

22. In your opinion, how important are the following features of hunting experience and consequences of hunting?

Feature	Importance of the Feature: Very Low 1	2	High 3	4	Very 5	Unsure
Provides an additional income	❑	❑	❑	❑	❑	❑
Increases value of the land	❑	❑	❑	❑	❑	❑
Shows a better stewardship of the land	❑	❑	❑	❑	❑	❑
Provides economic opportunities for the local community	❑	❑	❑	❑	❑	❑
Provides enjoyment/recreation to me and my family	❑	❑	❑	❑	❑	❑
Potential liability for user's injuries	❑	❑	❑	❑	❑	❑
Hunters' misconduct (vandalism, drinking, etc.)	❑	❑	❑	❑	❑	❑
Trespassing by non-approved individuals	❑	❑	❑	❑	❑	❑
Concern with the personal safety of my family and other people who work on my land	❑	❑	❑	❑	❑	❑
Damage to crops by hunters	❑	❑	❑	❑	❑	❑
Decreases damage to crops by reducing nuisance wildlife						
Presence of hunters will interfere with my farm operations	❑	❑	❑	❑	❑	❑
Other ____________	❑	❑	❑	❑	❑	❑
Other ____________	❑	❑	❑	❑	❑	❑

23. In your opinion, is there a potential for developing a market for hunting associated with in-field shelterbelts that would provide landowners, such as yourself, with an acceptable annual income source?

❑ Yes ⟶ *Please indicate strength of potential:*

❑ Weak ❑ Moderate ❑ Strong

❑ No

❑ Unsure

24. **Whether or not you currently allow hunting on your land**, we are interested in your willingness to allow additional hunters to access your land.

- How much monetary compensation would you need to grant hunting rights to hunt **pheasants** on your land?
- Please indicate **compensation needed and number of hunters in a party per visit** that you would allow for that compensation. By visit we mean any part of the day that you arrange with hunter/hunters to hunt on your land. Please check only one box.

❑ $0 per visit per party	No. of hunters per party _____
❑ $10 per visit per party	No. of hunters per party _____
❑ $30 per visit per party	No. of hunters per party _____
❑ $50 per visit per party	No. of hunters per party _____
❑ $70 per visit per party	No. of hunters per party _____
❑ $90 per visit per party	No. of hunters per party _____
❑ $110 per visit per party	No. of hunters per party _____
❑ more than $110 per visit per party	No. of hunters per party _____

❑ I wouldn't allow hunting pheasants on my land

25. What other game wildlife could potentially allow to be hunted on your land adjacent to in-field shelterbelt? Please check all that apply.

❑ Deer	❑ Rabbit	❑ Quail
❑ Wild turkey	❑ Squirrel	❑ Goose
❑ Raccoon	❑ Groundhog	❑ Duck
❑ Opossum	❑ Pheasant	❑ Other: __________
❑ Fox	❑ Partridge	❑ Other: __________
❑ Coyote	❑ Grouse	❑ Other: __________

4

In this section we would like to ask you some questions about you, other members of your household and your farmland.

26. What was your age on your last birthday?

- ❑ Under 25
- ❑ 26-35
- ❑ 36-45
- ❑ 46-55
- ❑ 56-65
- ❑ 66 years or older

27. What is your gender?

- ❑ Male
- ❑ Female

28. What is the highest level of education that you have completed?

- ❑ Some high school or less
- ❑ High school graduate (includes GED)
- ❑ Vocational or technical diploma or certificate
- ❑ Some college
- ❑ College graduate (Bachelor's Degree)
- ❑ Advanced college graduate (Master's Degree, Ph.D. or other)

29. How many people live in your household (including you)?

____

30. How many members of your household (including you) work full-time on your farm?

____

31. What was the gross (before taxes) income of all members of your household in year 2003?

- ❑ Less than $39,999
- ❑ $40,000-$79,999
- ❑ $80,000-$120,000
- ❑ more than $120,000

32. Where do you live?

- ❑ On farm
- ❑ In rural area but not on farm
- ❑ In town less than 2,500
- ❑ In town of 2,501 up to 5,000
- ❑ In town of 5,001 up to 10,000
- ❑ In town of 10,001 up to 50,000
- ❑ In a city of 50,000 or more

33. How many acres did you farm (own or rented) in 2003?

- ❑ Under 300 acres
- ❑ 301-700 acres
- ❑ 701-1100 acres
- ❑ over 1100 acres

☺ **Thank you for your participation in this survey.** We appreciate your time and effort. If you have any comments or suggestions regarding this questionnaire, please provide them below.

We value your comments and suggestions:

CHAPTER 5: GENERAL CONCLUSIONS

In-field shelterbelts provide not only valuable conservational benefits, but also can increase value of agricultural production. Although their benefits have been widely advocated, agricultural producers are reluctant to plant them due to their uncertain economic efficacy. There is a compelling need to examine economic viability of in-field shelterbelts to provide agricultural producers with information that will allow them make economically-effective decisions about their in-field shelterbelts. Such information will also be useful to various agencies that provide financial assistance to in-field shelterbelt owners to ensure that financial resources invested in planting in-field shelterbelts provide the maximum amount of desired benefits.

This dissertation explores the economic viability of major three in-field shelterbelt benefits: crop yield increase within the leeward sheltered zone of the in-field shelterbelt, carbon sequestration in woody biomass of in-field shelterbelt, and hunting opportunities on lands adjacent to in-field shelterbelts. Although these benefits have been extensively described in the literature, their economic implications have not been fully explored.

Additional crop yield required to break even

Effectiveness of in-field shelterbelts in terms of additional crop production was evaluated by estimation of additional corn yields required to offset establishment and management costs for selected in-field shelterbelt designs. In-field shelterbelts that require smaller additional corn yields to break even are better because it is more likely to achieve such yields.

The mixed in-field shelterbelt planted in extensive management at low cost and with a 50-year lifespan was identified as the most effective, because it required the smallest additional corn yields across three lengths of the sheltered zone (0.22 Mg ha^{-1} within 15H, 0.28 Mg ha^{-1} within 12H and 0.56 Mg ha^{-1} within 6H). A spruce shelterbelt planted in four rows in intensive management at high cost and with a 10-year lifespan required the greatest amounts of additional crop production (6.15 Mg ha^{-1} within 15H, 7.69 Mg ha^{-1} within 12H and 15.38 Mg ha^{-1} within 6H).

Whether or not a particular shelterbelt design breaks even depends on actual crop response to the sheltering effect. If crop response is poor – yield increase of 0.42 Mg ha^{-1}, then out of 240 examined designs only 21 break even. Whereas a more favorable response – yield increase of 8.9 Mg ha^{-1} causes 95 designs out of 240 to break even. A very optimistic scenario – yield increase of 1.34 Mg ha^{-1} causes 137 in-field shelterbelt designs to break even.

Analysis of increased crop yield revealed also that the financial criterion (NPV) should not be used as the sole measure for selecting the most efficient shelterbelt designs. In-field shelterbelt designs that were identified as least costly (e.g. spruce shelterbelt consisting of trees planted in two rows) required significantly greater additional corn yields to cover costs than more expensive ones (e.g. a mixed shelterbelt). In this study, costly in-field shelterbelts grow faster and taller, and, therefore, provide a sheltering effect over a larger area (a longer sheltered zone perpendicular to rows of trees) and reduce costs per unit area. Consequently, the additional corn yield required to offset costs are smaller.

Similarly, as the functional lifespan of an in-field shelterbelt is extended, the required additional corn yields decrease because costs are distributed over more years. Short lifespans are not necessarily economically feasible because they require large additional corn yields due to the high costs incurred during the first decade. The increase in additional corn yields required for lifespans longer than 30 years is relatively small, which gives agricultural producers some flexibility in selecting suitable design as well as reduces the uncertainty associated with shelterbelt long-term performance.

Carbon sequestration and in-field shelterbelts

The economic effectiveness of in-field shelterbelts in terms of carbon sequestration depends on the rate of carbon accumulation in their woody biomass in relation to the incurred costs. A shelterbelt's carbon accumulation depends on the vegetation's growth rate, tree/shrub density (spacing), the lifespan and area. In-field shelterbelts that are denser are better because they accumulate more carbon. Further, using fast-growing species is better too, because they accumulate required amounts of carbon sooner and, therefore, cause the in-field shelterbelt to break even with shorter lifespans.

Hardwood shelterbelts (4-row cottonwood and 2-row mixed shelterbelt) perform better than spruces (2 and 4-row) because they accumulate greater amounts of carbon over time. This economic analysis revealed that a cottonwood shelterbelt planted in four rows is the best because it accumulates the greatest amount of carbon over time and, therefore, allows agricultural producers to break even sooner. It is the only shelterbelt (out of examined ones) to break even within the maximum 50-year lifespan. If both above-ground and below-ground carbon are accounted for, then it is possible to break even with lifespan as short as 30 years. If only above-ground carbon is included in analysis then more time (40 years) is needed to offset shelterbelt costs. Other shelterbelts require greater amounts of carbon to break even, which cannot be achieved even within a 50-year lifespan.

Viability of carbon sequestration by in-field shelterbelts will depend to a large extent on emerging carbon market. Higher prices will allow to break even with shorter lifespans. In-field shelterbelts designed for maximization of benefits other than carbon sequestration may be able to break even too.

CRP payments are desirable from landowner perspective because they offset majority of costs and allow to break even also with less effective designs. This is especially useful to landowners who wish to optimize for other benefits.

Hunting and in-field shelterbelts

A study conducted to assess the opportunity of hunting on lands adjacent to and including in-field shelterbelts revealed that a majority (55%) of agricultural producers believe that there is potential for developing a fee hunting market. However, they indicate that the potential is either week or moderate. Intangible benefits of hunting such as recreation/enjoyment and better stewardship are assigned a higher level of importance than monetary benefits such as providing additional income and economic opportunities for the local community. This importance array is attributable to the respondents' beliefs and values related to free hunting and may be due to a limited experience with fee hunting as well. Nearly all respondents (95%) allow some hunting by themselves, friends, neighbors and free hunting to anyone. Respondents, however, are highly concerned with some negative effects of hunting such trespassing and hunter misconduct. Agricultural producers wish to control the number of hunters accessing their land. On average, they will allow four hunters in a party and require $22.74 per visit per party to allow additional hunters access their land to hunt pheasants. However, there is a large number of producers who will not charge any fee. Statistical analysis revealed that willingness to accept monetary compensation (WTA) for granting hunting privileges can be better predicted based on attitude variables than on socioeconomic variables. This suggests that WTA is more influenced by personal beliefs about hunting than by perceived economic opportunities.

Although many of the benefits associated with in-field shelterbelts are difficult to express in monetary terms, most agricultural producers in this study believe that the benefits outweigh associated costs. However, the assessment is rather heuristic than based on economic analysis. It is necessary to emphasize that many producers obtained some financial assistance to establish their shelterbelts, which may have influenced their favorable assessment. To illustrate, some producers pointed out that without such assistance many of the shelterbelts probably would not be planted.

Overall, my analyses show that in-field shelterbelts can be economically effective if properly designed. However, a relatively long period of time is required to offset the costs associated with its establishment and management. A particular design will depend on landowner expected benefits. An in-field shelterbelt that is optimal for one benefit such as wind protection is not necessarily optimal for another such as wildlife habitat or carbon sequestration. Economic viability of the in-field shelterbelt depends not only on incurred costs but also on the biological capacity of the trees planted. Therefore, selection of appropriate species is also crucial for attaining desired benefits and reaching break-even points.